EPA/DOE

MINE WASTE TECHNOLOGY PROGRAM

Technology Testing for Tomorrow's Solutions

2003 ANNUAL REPORT

MINE
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TECHNOLOGY
PROGRAM

EPA DOE Montana Tech Implemented by MSE Technology Applications, Inc.

EPA/DOE

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2003 ANNUAL REPORT

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Mine Waste Technology Program
Interagency Agreement Management Committee
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Prepared for:

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VISION STATEMENT FOR THE MINE WASTE TECHNOLOGY PROGRAM

BACKGROUND

Mining activities in the United States (not counting coal) produce between 1 and 2 billion tons of mine waste annually. These activities include extraction and beneficiation of metallic ores, phosphate, uranium, and oil shale. Over 130,000 of these noncoal mines, concentrated largely in nine western states, are responsible for polluting over 3,400 miles of streams and over 440,000 acres of land. About seventy of these sites are on the National Priority List for Superfund remediation. In the 1985 Report to Congress on the subject, the total noncoal mine waste volume was estimated at 50 billion tons, with 33% being tailings, 17% dump/heap leach wastes and mine water, and 50% surface and underground wastes. Since many of the mines involve sulfide minerals, the production of acid mine drainage (AMD) is a common problem from these abandoned mine sites. The cold temperatures in the higher elevations and heavy snows frequently prevent winter site access. The combinations of acidity, heavy metals, and sediment have severe detrimental environmental impacts on the delicate ecosystems in the West.

PHILOSOPHY/VISION

End-of-pipe treatment technologies, while essential for short-term control of environmental impact from mining operations, are a stopgap approach for total remediation. Efforts need to be made on improving the end-of-pipe technologies to reduce trace elements to low levels for applications in ultra-sensitive watersheds and for reliable operation in unattended, no power situations. The concept of pollution prevention, emphasizing at-source control and resource recovery, is the approach of choice for the long-term solution. Our objective in the Mine Waste Technology Program is not to assess the environmental impacts of the mining activities, but it is to develop and prove technologies that provide satisfactory short- and long-term solutions to the remedial problems facing abandoned mines often in remote sites and the ongoing compliance problems associated with active mines.

APPROACH

There are priority areas for research, in the following order of importance:

Source Controls, Including In Situ Treatments and Predictive Techniques
It is far more effective to attack the problem at its source than to attempt to deal with diverse and dispersed wastes, laden with wide varieties of metal contaminants. At-source control technologies, such as sulfate-reducing bacteria; biocyanide oxidation for heap leach piles; transport control/pathway interruption techniques, including infiltration controls, sealing, grouting, and plugging by ultramicrobiological systems; and AMD production prediction and control techniques should strive toward providing a permanent solution, which is the most important goal of the program.

Treatment Technologies
Improvements in short-term end-of-pipe treatment options are essential for providing immediate alleviation of some of the severe environmental problems associated with mining, and particularly with abandoned metal mines. Because immediate solutions may be required, this area of research is extremely important for effective environmental protection.

Resource Recovery
In the spirit of pollution prevention, much of the mining wastes, both AMD (e.g., *over 25 billion gallons* of Berkeley Pit water) and the billions of tons of mining/beneficiation wastes, represent a potential resource as they contain significant quantities of heavy metals. While remediating these wastes, it may be feasible to incorporate resource recovery options to help offset remedial costs.

THE PARTNERSHIPS

In these days of ever-tightening budgets, it is important that we leverage our limited funding with other agencies and with private industry. The Bureau of Land Management and Forest Service actively participate by providing sites for demonstrations of the technologies. It is important where these technologies have application to active mining operations to achieve cost-sharing partnerships with the mining industry to test the technologies at their sites. Fortunately, the program has strong cooperation from industry. Within the U.S. Environmental Protection Agency (EPA), the program is coordinated and teamed, where appropriate, with the Superfund Innovative Technology Evaluation (SITE) program to leverage the funding and maximize the effectiveness of both programs. We have strong interaction, cooperation, and assistance from the mining teams in the EPA Regional Offices, especially Regions 7, 8, 9, and 10. Several joint projects are underway, and more are planned.

A considerable resource and willing partner is the University system (such as Montana Tech of the University of Montana, University of Montana–Missoula, Montana State University–Bozeman, and the Center for Biofilm Engineering), which can conduct the more basic type of research related to kinetics, characterization, and bench-scale tests at minimal cost to the program, while at the same time providing environmental education that will be useful to the region and to the Nation. The Mine Waste Technology Program supports cooperative projects between the educational system and the mining industry, where teams of students conduct research of mine site-specific problems, often with monetary support from the industry. The results are made available to the industry as a whole and to the academic community.

THE SCIENCE

The research program is peer-reviewed annually by the Technical Integration Committee (TIC), who technically reviews all ongoing and proposed projects. The TIC is composed of technical experts from EPA and the cooperating agencies, academia, environmental stakeholders, and industry and their consultants. Final reports are additionally peer-reviewed in accordance with EPA's strict policy for scientific products.

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PROGRAM MANAGER'S EXECUTIVE SUMMARY

The Mine Waste Technology Program (MWTP) Annual Report for fiscal 2003 summarizes the results and accomplishments for the various activities within the Program. The MWTP has met its goals by providing assistance to the public and forming cooperative teams drawn from government, industry, and private citizens. The funds expended have returned tangible results, providing tools for those faced with mine waste remediation challenges.

After 13 years, everyone involved with the MWTP can look with pride to the Program's success. Technology development and basic research has proceeded successfully through the efforts of MSE Technology Applications, Inc. (MSE) and its prime subcontractor Montana Tech of the University of Montana (Montana Tech).

MSE has developed thirty-seven field-scale demonstrations, several of which are attracting attention from industry and public stakeholders involved in the cleanup of mine wastes.

Montana Tech has developed twenty-four bench-scale projects, six of which are ongoing during 2003. This cooperative effort provides cutting edge research for the program as well as educational opportunities.

Numerous activities are associated with the development of a field-scale demonstration. Among these activities is the need to acquire federal and state permits; secure liability limiting access agreements; develop and adhere to health and safety operation plans and quality assurance project plans; and comply with the National Environmental Policy Act and other federal and state environmental oversight statutes.

The Program has received substantial support from state and federal agencies, the mining industry, environmental organizations, and numerous associations interested in mining and development of natural resources at state, regional, and national levels.

Montana Tech continued the post-graduate degree program with a mine waste emphasis. The quality of short courses offered by Montana Tech is becoming highly recognized by the mining industry and mine waste remediation community. Graduates of the program are fast becoming leaders for industry and government agencies helping to promote technology usage and acceptance worldwide.

The MWTP recognizes its major accomplishments and looks forward to providing new and innovative technologies; meeting the challenges of mine waste remediation; and providing economical, permanent solutions to the nation's mining waste problems.

Jeff LeFever
MSE MWTP Program Manager

INTRODUCTION

Mining waste generated by active and inactive mining production facilities and its impact on human health and the environment are a growing problem for Government entities, private industry, and the general public. The nation's reported volume of mine waste is immense. Presently, there are more than sixty mining impacted sites on the U.S. Environmental Protection Agency's National Priorities List.

Environmental impacts associated with inactive and abandoned mines are common to mining districts around the country, as shown in Table 1.

Total estimated remediation costs for these states range from $4 to $45 billion.

Health effects from the predominate contaminants in mine waste range from mild irritants to proven human carcinogens, such as cadmium and arsenic. The large volume of mine wastes and consequential adverse environmental and human health effects indicates an urgency for cleanup of abandoned, inactive, and active mining facilities. The environmental future of the United States depends in part on the ability to deal effectively with mine waste problems of the past and present, and more importantly, to prevent mine waste problems in the future.

The fiscal year (FY) 1991 Congressional Appropriation allocated $3.5 million to establish a pilot program in Butte, Montana, for evaluating and testing mine waste treatment technologies. The Mine Waste Technology Program (MWTP) received additional appropriations of $3.5 million in FY91, $3.3 million in FY94, $5.9 million in FY95, $2.5 million in FY96, $7.5 million in FY97, $6.0 million in FY98 and FY99, $4.3 million in FY00, $3.9 million in FY01, $3.9 million in FY02, and $3.5 million in FY03.

The projects undertaken by this Program focus on developing and demonstrating innovative technologies at both the bench- and pilot-scale that treat wastes to reduce their volume, mobility, or toxicity. Fifty percent of the budget is allocated to focus areas such as: 1) source control for preventing metal leaching and acid mine drainage; 2) techniques for treating low-flow metal laden/acid mine drainage in remote settings. To convey the results of these demonstrations to the user community, the mining industry, and regulatory agencies, MWTP includes provisions for extensive technology transfer and educational activities. This report summarizes the progress of the MWTP activities in FY03.

Table 1. Number and types of sites and abandoned mine lands in Western Region

State	Estimated Number of Sites or Land Areas	Classification and Estimated Number
Alaska	10,910 sites	mine dumps - 1,000 acres disturbed land - 27,680 acres mine openings - 500 hazardous structures - 300
Arizona	95,000 sites	polluted water - 2,002 acres mine dumps - 40,000 acres disturbed land - 96,652 acres mine openings - 80,000
California	11,500 sites	polluted water - 369,920 acres mine dumps - 171 acres mine openings - 1,685
Colorado	20,229 sites covering 26,584 acres	polluted water - 830,720 acres mine dumps - 11,800 acres disturbed land - 13,486 acres mine openings - 20,229 hazardous structures - 1,125
Idaho	8,500 sites covering 18,465 acres	polluted water - 84,480 acres mine dumps - 3,048 acres disturbed land - 24,495 acres mine openings - 2,979 hazardous structures - 1,926
Michigan	400–500 sites	Accurate information not available.
Montana	19,751 sites covering 11,256 acres	polluted water - 715,520 acres mine dumps - 14,038 acres disturbed land - 20,862 acres mine openings - 4,668 hazardous structures - 1,747
Nevada	400,000 sites	Accurate information not available.
New Mexico	7,222 sites covering 13,585 acres	polluted water - 44,160 acres mine dumps - 6,335 acres disturbed land - 25,230 acres mine openings - 13,666 hazardous structures - 658
Oregon	3,750 sites	polluted water - 140,800 acres mine dumps - 180 acres disturbed land - 61,000 acres mine openings - 3,750 hazardous structures - 695
South Dakota	4,775 acres	Accurate information not available.
Texas	17,300 acres	Accurate information not available.
Utah	14,364 sites covering 12,780 acres	polluted water - 53,120 acres mine dumps - 2,369 acres disturbed land - 18,873 acres mine openings - 14,364 hazardous structures - 224
Wisconsin	200 acres	Accurate information not available.
Wyoming	5,000 acres	Accurate information not available.

Information was collected from the following sources and is only an estimate of the acid mine drainage problem.

-Bureau of Land Management
-Bureau of Mines
-Mineral Policy Center
-National Park Service
-U.S. Department of Agriculture
-U.S. Department of the Interior
-U.S. Forest Service
-U.S. Geological Survey
-U.S. General Accounting Office
-Western Governor's Association Mine Waste Task Force Study

PROGRAM OVERVIEW

FISCAL 2003 PROGRAM

This Mine Waste Technology Program (MWTP) annual report covers the period from October 1, 2002, through September 30, 2003. This section of the report explains the MWTP organization and operation.

MISSION

The mission of the MWTP is to provide engineering solutions to national environmental issues resulting from the past practices of mining and smelting of metallic ores. In accomplishing this mission, the MWTP develops and conducts a program that emphasizes treatment technology development, testing and evaluation at bench- and pilot-scale, and an education program that emphasizes training and technology transfer. Evaluation of the treatment technologies focuses on reducing the mobility, toxicity, and volume of waste; implementability; short- and long-term effectiveness; protection of human health and the environment; community acceptance; and cost reduction.

The statement of work provided in the Interagency Agreement between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy identifies six activities to be completed by MWTP. The following descriptions identify the key features of each and the organization performing the activity.

ACTIVITY I: ISSUES IDENTIFICATION

Montana Tech of the University of Montana (Montana Tech) is documenting various mine waste technical issues and innovative treatment technologies. These issues and technologies are then screened and prioritized in volumes related to a specific mine waste problem. In 2003, Volume 10, *Issues Identification and Technology Prioritization Report–Mercury,* was published. The Berkeley Pit monograph report titled *A Summary of Berkeley Pit Research: The Resource Recovery and Mine Waste Technology Programs* was also published. Technical issues of primary interest include numerous mobile toxic constituents such as arsenic, cyanide, mercury, nitrate, selenium, and thallium as well as sulfate-reducing bacteria, water/acid generation, pyrite-rich mine wastes, and pit lakes. Wasteforms reviewed related to these issues included point- and nonpoint-source acid mine drainage, abandoned mine acid mine drainage, streamside tailings, impounded tailings, soils, and heap leach-cyanide/acid tailings. Furthermore, under this task, Montana Tech produced an interactive CD-ROM based summary of the program including the Annual Report and Activities in Depth CD, Snapshot CD (Version 1.0 and 2.1), and Combo CD (Version 3.1). The CDs can be obtained from the personnel listed in the Contacts Section of this report. Various personnel contacts and research information are also available on the web at: http://www.epa.gov/ORD/NRMRL/std/mtb.

ACTIVITY II: QUALITY ASSURANCE

The MWTP operates under an EPA approved Quality Management Plan (QMP). The QMP is available on www.epa.gov/ORD/NRMRL/std/mtb. This plan provides specific instructions for data gathering, analyzing, validating, and reporting for all MWTP activities. The QMP also contains guidance related to program roles and responsibilities, training, work flow processes, oversight, corrective action procedures, and quality improvement. In addition to the QMP, each MWTP project is performed under the auspices of an EPA-approved Quality Assurance Project Plan.

ACTIVITY III: PILOT-SCALE DEMONSTRATIONS

Pilot-scale demonstration topics were chosen after a thorough investigation of the associated technical issues was performed, the specific wasteform to be tested was identified, peer review was conducted, and sound engineering and cost determination of the demonstration were formulated.

MSE continued fourteen field-scale demonstrations during fiscal 2003. One field demonstration was completed, i.e., Project 36.

ACTIVITY IV: BENCH-SCALE EXPERIMENTS

Montana Tech had eight ongoing projects during fiscal 2003. Five projects were begun: 1) Project 25–Metal Remediation/Cementation; 2) Project 26–Organic Matter–Phase 2; 3) Project 27–Subaqueous Pyrite Oxidation; 4) Project 28–Mercury Transportation from Reclaimed Mine Sites; and 5) Project 29–Monitoring and Evaluation of Remediation Strategies in the Helena National Forest.

ACTIVITY V: TECHNOLOGY TRANSFER

MSE is responsible for preparing and distributing reports for the MWTP. These include routine weekly, monthly, quarterly, and annual reports; technical progress reports; and final reports for all MWTP activities. MSE also publicizes information developed under MWTP in local, regional, and national publications. Other means of information transfer include public meetings, workshops, and symposiums.

ACTIVITY VI: EDUCATIONAL PROGRAMS

Montana Tech has developed a post-graduate degree program with a mine waste emphasis. The program contains elements of geophysical, hydrogeological, environmental, geochemical, mining and mineral processing, extractive metallurgical, and biological engineering.

ORGANIZATIONAL STRUCTURE

MANAGEMENT ROLES AND RESPONSIBILITIES

Management of the Mine Waste Technology Program (MWTP) is specified in the Interagency Agreement. The roles and responsibilities of each organization represented are described below. The MWTP organizational chart is presented in Figure 1.

U.S. ENVIRONMENTAL PROTECTION AGENCY

The Director of the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio, is the principal U.S. Environmental Protection Agency Office of Research and Development representative on the Interagency Agreement Management committee. NRMRL personnel are responsible for management oversight of technical direction, quality assurance, budget, schedule, and scope.

U.S. DEPARTMENT OF ENERGY

The Director of the National Energy Technology Laboratory (NETL) is the principal U.S. Department of Energy (DOE) representative on the Interagency Agreement Management committee. NETL personnel provide contract oversight for the MWTP. MSE Technology Applications, Inc. (MSE) is responsible to NETL for adherence to environmental, safety and health requirements; regulatory requirements; National Environmental Protection Act requirements, and conduct of operations of all projects.

MSE TECHNOLOGY APPLICATIONS, INC.

MSE, under contract with DOE, is the principal performing contractor for MWTP. The MWTP Program Manager is the point of contact for all MWTP activities. The Program Manager is responsible for program management and coordination, program status reporting, funds distribution, and communications.

An MSE project manager has been assigned to each MWTP project and is responsible to the MWTP Program Manager for overall project direction, control, and coordination. Each project manager is responsible for implementing the project within the approved scope, schedule, and cost. MSE also provides all staff necessary for completing Activities II, III and V and oversight of Activities III, IV, and VI.

MONTANA TECH OF THE UNIVERSITY OF MONTANA

As a subcontractor to MSE, Montana Tech of the University of Montana is responsible to the MWTP Program Manager for all work performed under Activities I, IV, and VI. The responsibility for overall project direction, control, and coordination of the work to be completed by Montana Tech is assigned to the MWTP Montana Tech Project Manager.

TECHNICAL INTEGRATION COMMITTEE

The Technical Integration Committee (TIC) serves several purposes in the MWTP organization: 1) TIC reviews new proposals and ranks them at a meeting held in Butte, Montana; 2) it reviews progress in meeting the goals of the MWTP and alerts the Interagency Agreement Management Committee to pertinent technical concerns; 3) it provides information on the needs and requirements of the entire mining waste technology user community; and 4) it assists with evaluating technology demonstrations as well as technology transfer. This committee is comprised of representatives from both the public and private sectors.

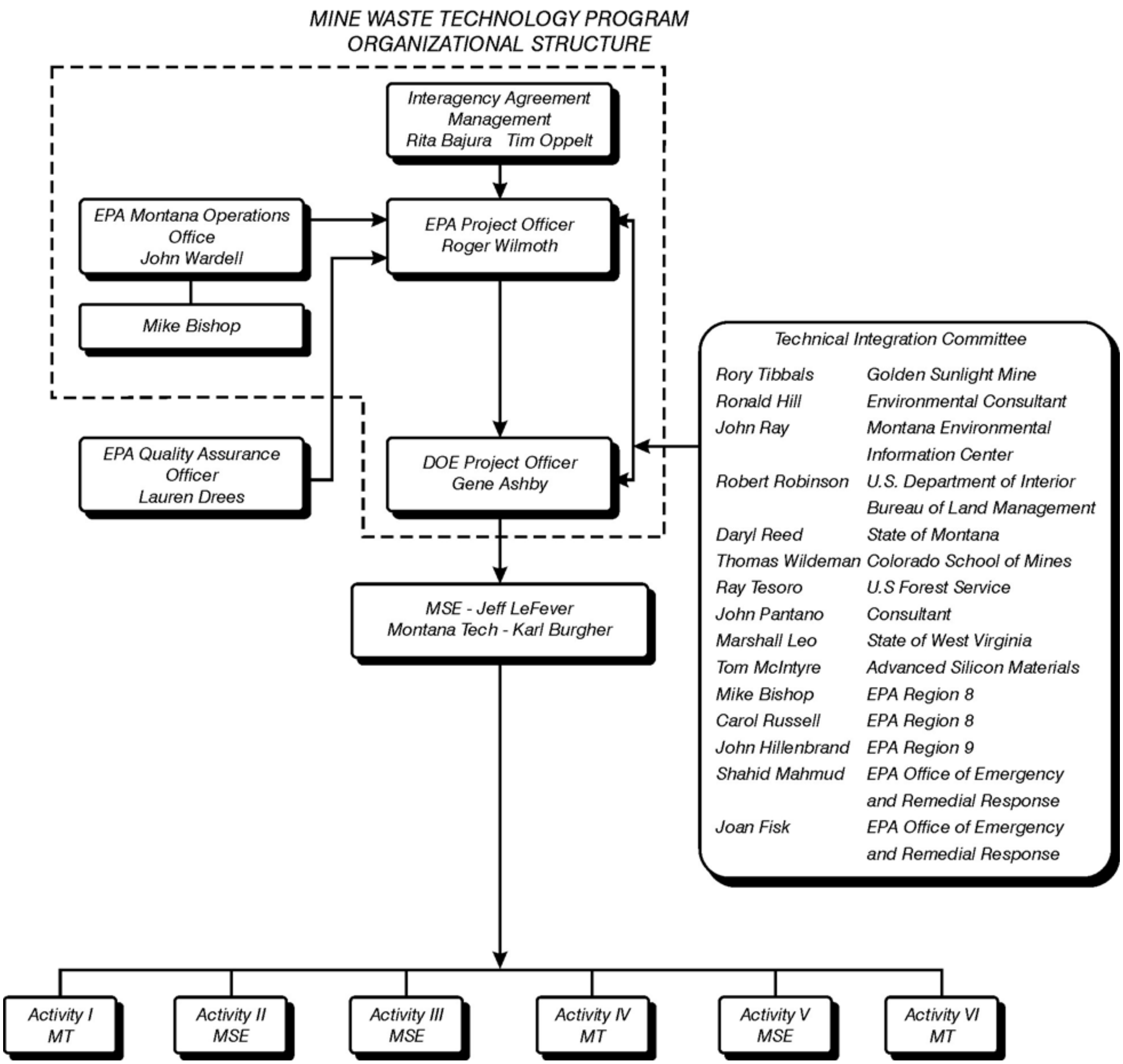


Figure 1. MWTP organizational chart.

LOOKING AHEAD TO FY04

During FY04, the following additional projects will be funded under Activity III of the MWTP.

Project 28—Mine Site Telemetry
This project will evaluate the performance of a fuel cell supplied by the DOE National Energy Technology Laboratory as the power source for instrumentation and equipment at a remote mine site.

Project 41—Update of Case Studies
This project will complete three case studies on mine sites initially done using funding from the EPA Superfund Innovative Technology Evaluation Program. The work will include comment incorporation from reviewers as well as updated information about each site. The three sites profiled in the original document included: Gilt Edge Mine in South Dakota; the Leviathan Mine in California; and the Golden Sunlight Mine in Montana.

Project 42—Physical Solutions for Acid Mine Drainage at Remote Sites
This project will evaluate a technology for the removal of heavy metals from acid mine drainage in the Ten Mile Creek area of Montana in support of EPA Region 8. The FY04 scope includes bench-scale evaluations of simple technologies for treating up to five different waters, the combination of three waters from the Ten Mile Creek area, as well as one water from the ASARCO smelter in Montana City, Montana.

Project 43—Thallium Removal from Mine Waste Waters
This project will further evaluate the thallium removal technology developed under Activity IV, Project 12 of the MWTP. The purpose of the evaluation is to further develop the technology, particularly the engineering aspects. A bench-scale demonstration is planned. If successful, the technology may eventually be scaled-up and demonstrated at a pilot-scale level in the field.

Project 44—Remediation of Underground Mines Using Source Control/Passive Technologies
This project will use a combination of two technologies to accomplish the remediation of an underground mine system. A source control (grouting) technology will be used to reduce the flow in the underground mine workings. A second, passive water treatment technology will be used to treat residual water discharging from the adit. The combination of the technologies is expected to increase the efficiency, longevity, and decrease the cost to operate the passive treatment system.

Project 45—Microbial and Geochemical Responses in Acid Producing Mine Tailings
This project will evaluate, at laboratory scale, the geochemical properties of mine tailings when microbes are used as the treatment technology. This project builds on the MWTP experience using sulfate-reducing bacteria and other microbes to treat AMD but focuses on the mineral forms that result from the microbial action.

Project 46—Cyanide Heap Biological Detoxification, Phase II
This demonstration will be conducted at the Gold Acres Heap Leach Pad located at Placer Dome's Cortez Gold Mine in Crescent Valley, Nevada. The biological technology owned by Whitlock & Associates of Spearfish, South Dakota, will be used to destroy the cyanide present. The effect of the technology on heavy metals of concern will also be monitored. Column studies will be performed before application of the technology in the field.

Similarly, during FY04, the following new Montana Tech of the University of Montana Projects (Activity IV) will be funded.

Project 30—Berkeley Pit Limnocorrals
Limnocorrals have been used for about 40 years for experimental studies in lakes when it is necessary to test biological, physical, and chemical properties in situ while varying an aspect of the ecosystem on a small scale to determine the outcome. This project will test bioremediation potential in situ using limnocorrals with nitrification and inoculation with the algae as variables.

Project 31—Modified Ferrihydrite for Enhanced Removal of Arsenic from Mine Wastewater
The purpose of this study is to investigate the adsorption characteristics of ferri-oxyhydroxide (ferrihydrite) and aluminum-modified ferrihydrite for removal of arsenate and arsenite species under various conditions that vary with respect to the iron/arsenic ratio, initial arsenic concentration, arsenic valence (III and/or V), aluminum content in the aluminum-modified ferrihydrite, and pH. The relative stability of the final products will be determined and compared to products from unmodified ferrihydrite. Stability testing will be performed at elevated temperatures to accelerate crystallization kinetics and aging characteristics of ferrihydrite, aluminum-modified ferrihydrite, arsenic loaded ferrihydrite, and arsenic loaded aluminum-modified ferrihydrite solids.

Project 32—Geochemistry and Isotopic Composition of H_2S-Rich Water in Flooded Underground Mine Workings, Butte, Montana
The purpose of this study will be to collect water samples from Butte's West Camp for comprehensive chemical and isotopic analysis and to combine these results with geochemical modeling to more fully understand the processes that control the geochemistry of the West Camp mine waters in Butte, Montana.

Project 33—CALPUFF Modeling of Copper Smelter Emissions
The goal of this project is to use advanced features of the CALPUFF modeling system to study the impact of the Anaconda smelter plume throughout the region. The project will be the first of its kind to use the CALPUFF modeling system to simulate impact from the Anaconda smelter stack. The three primary objectives of the project are: 1) to predict potential hotspots of contamination on the terrain from short- and long-range transport of the smelter plume; 2) to compare modeled hotspots with existing soil data; and 3) to identify sites that may warrant further investigation and remediation.

Project 34—Passive Remediation of Sulfide Wastes Through Utilization of Composite Covers, Lime, and Controlled Oxygen Diffusion: A Study of Diffusion Rates Through Composite Covers of Varying Saturation
Caps and covers are frequently prescribed to limit the access of oxygen and water to sulfide waste materials in an effort to limit the future production of acid rock drainage. The range of capping alternatives presently employed or being proposed varies widely. The objective of this research is to recreate, in diffusion cells, sample capping scenarios for the mine waste closure of potentially acid generating materials with lime as an amendment. The cell will then be used to measure oxygen flux under a scale of saturation conditions that would accurately describe the oxygen diffusion through the capping alternatives presently being prescribed in the field.

ACTIVITIES

DESCRIPTIONS, ACCOMPLISHMENTS, AND FUTURE DIRECTION

This section describes the Mine Waste Technology Program (MWTP) Activities I through VI and includes project descriptions, major project accomplishments during fiscal 2003, and future project direction.

ACTIVITY I OVERVIEW—ISSUES IDENTIFICATION

This activity focuses on documenting mine waste technical issues and identifying innovative treatment technologies. Issues and technologies are screened and prioritized in volumes related to a specific mine waste problem/market.

Following completion of a volume, appendices are prepared. Each appendix links a candidate technology with a specific site where such a technology might be applied. The technology/site combinations are then screened and ranked.

Technical Issue Status

The status of the volume documents approved for development includes:

- Volume 1, Mobile Toxic Constituents—Water and Acid Generation, complete.
  - Appendix A–Remote Mine Site, complete;
  - Appendix B–Grouting, complete; and
  - Appendix C–Sulfate-Reducing Bacteria, complete.
- Volume 2, Mobile Toxic Constituents—Air, complete.
- Volume 3, Cyanide, complete.
  - Appendix A–Biocyanide, complete.
- Volume 4, Nitrate, complete.
- Volume 5, Arsenic, complete.
- Volumes 1-5 Summary Report, complete.
- Volume 6, Pyrite, complete.
- Volume 7, Selenium, complete.
- Volume 8, Thallium, complete.
- Volume 9, Pit Lakes, in progress.
- Volume 10, Mercury, complete.

These documents can be reviewed at the web site, www.epa.gov/ORD/NRMRL/std/mtb.

ACTIVITY II OVERVIEW—QUALITY ASSURANCE

The objective of this activity is to provide support to individual MWTP projects by ensuring all data generated is legally and technically defensible and that it supports the achievement of individual project objectives. The primary means of carrying out this activity is the Quality Assurance Project Plan (QAPP), which is written for each project and approved by the U.S. Environmental Protection Agency (EPA) prior to data collection. This plan specifies the quality requirements the data must meet, states the project objectives, describes all sampling and measurement activities, and contains standard operating procedures, when applicable. The QAPPs are reviewed by the EPA-National Risk Management Research Laboratory (NRMRL) QA Manager and EPA-NRMRL Project Manager. All comments are addressed, and the document is approved prior to data collection. Other functions of this activity include assessing projects, validating data, implementing corrective action, and reporting to project management.

The EPA approved the MWTP Quality Management Plan in 200l. The MWTP Quality Management Plan is updated annually. The EPA-NRMRL assesses the MWTP Quality System every 3 years and performs one or more technical system reviews annually.

ACTIVITY III OVERVIEW—PILOT-SCALE DEMONSTRATIONS

The objective of this activity is to demonstrate innovative and practical remedial technologies at selected waste sites, a key step in proving value for widespread use and commercialization. Technologies and sites are selected primarily from projects selected by the Technical Integration Committee, the prioritized lists generated in the Volumes from Activity I, or they may be a scale-up from bench-scale experiments conducted under Activity IV.

ACTIVITY III, PROJECT 3: SULFATE-REDUCING BACTERIA DEMONSTRATION

Project Overview

This project focuses on an acid mine drainage source-control technology that can significantly retard or prevent acid generation at affected mining sites. Biological sulfate reduction is being demonstrated at an abandoned hard-rock mine site where acid production is occurring with associated metal mobility.

Technology Description

For aqueous waste, this biological process is generally limited to the reduction of dissolved sulfate to hydrogen sulfide and the concomitant oxidation of organic nutrients to bicarbonate. The particular group of bacteria chosen for this demonstration, sulfate-reducing bacteria (SRB), require a reducing environment and cannot tolerate aerobic conditions for extended periods. These bacteria require a simple organic nutrient.

This technology can reduce the contamination of aqueous waste in three ways. First, dissolved sulfate is reduced to hydrogen sulfide through metabolic action by the SRB. Next, the hydrogen sulfide reacts with dissolved metals forming insoluble metal sulfides. Finally, the bacterial metabolism of the organic substrate produces bicarbonate, increasing the pH of the solution and limiting further metal dissolution.

At the acid-generating mine site chosen for the technology demonstration, the Lilly/Orphan Boy Mine near Elliston, Montana, the aqueous waste contained in the shaft is being treated by using the mine as an in situ reactor. A substrate composed of cow manure, wood chips, and alfalfa was added to promote growth of the organisms. This technology will also act as a source control by slowing or reversing acid production. Biological sulfate reduction is an anaerobic process that will reduce the quantity of dissolved oxygen in the mine water and increase the pH, thereby, slowing or stopping acid production.

The shaft of the Lilly/Orphan Boy Mine was developed to a depth of 250 feet and is flooded to the 74-foot level. Acid mine water historically discharged from the portal is associated with this level.

Pilot-scale work performed prior to the field demonstration determined how well bacterial sulfate reduction lowers the concentration of metals in mine water at the shaft temperature (8 ºC) and pH (3).

Status

Fiscal year 2003 was the ninth year of this field demonstration. Figure 2 shows a cross-section of the underground mine with the technology installation.

The analytical data generally demonstrates a decrease in dissolved metals concentrations as shown in Figure 3. Manganese, however, is not removed because SRBs are not effective in its removal. The plot indicates that during a spring runoff event there is a significant increase in dissolved metals concentrations; however, the levels decreased when flow rates returned to normal.

Two inlet sampling well points were installed in late FY03. Each was located at a potential feed source to the bioreactor. These sampling locations will be monitored to more fully assess the treatment being conducted and to provide greater confidence for project reporting activities. Sampling at these additional locations will assist in relating feed water origin to the treatment and effluent flows and in the characterization of water flow through the mine and treatment system. Sampling of this project is currently scheduled to continue through September 2004.

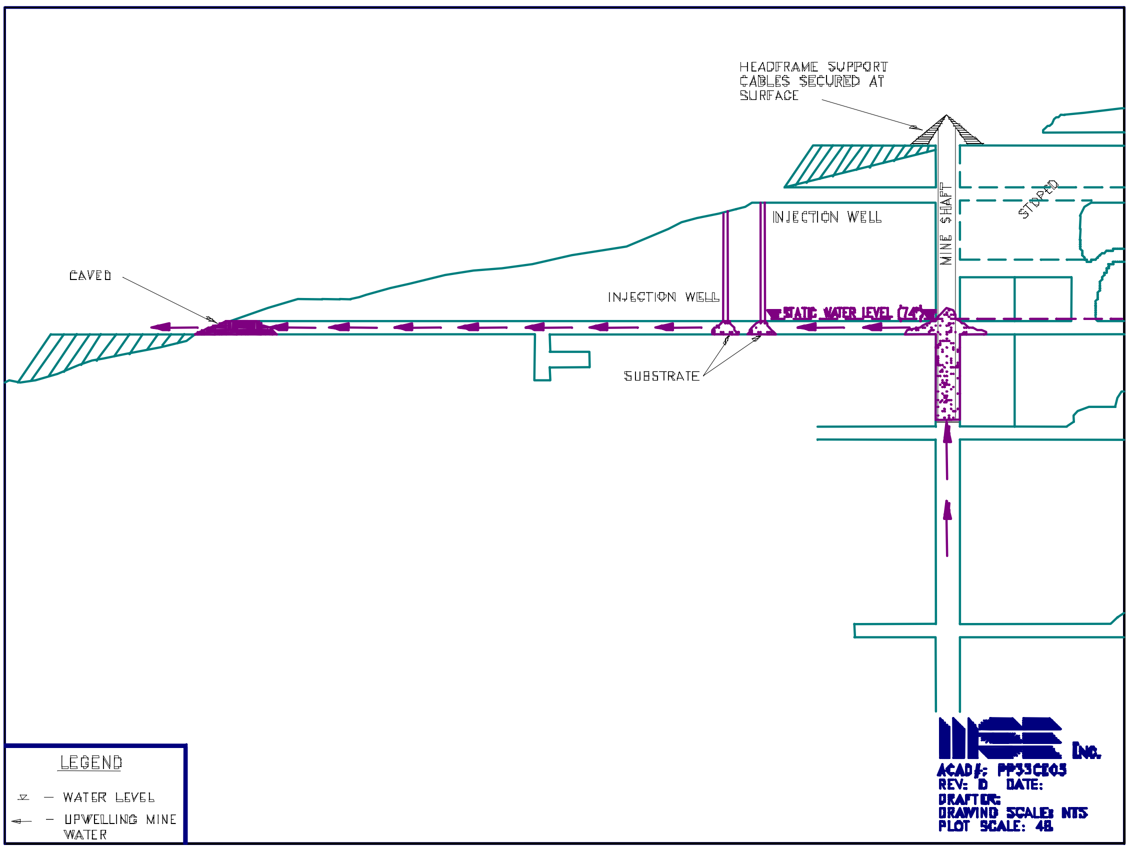


Figure 2. Cross-section of the Lilly/Orphan Boy Mine and the technology installation.

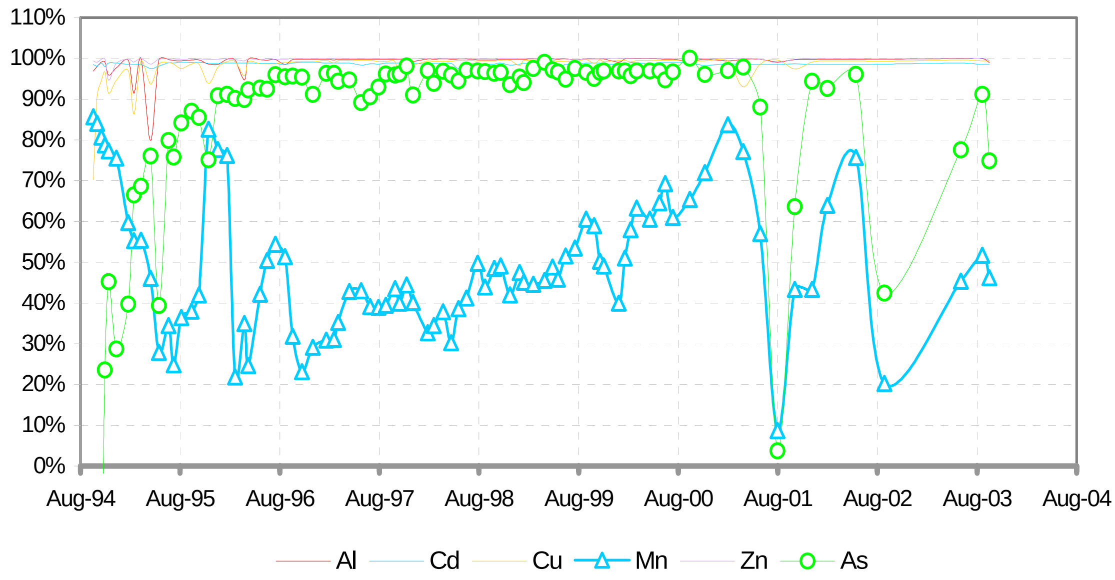


Figure 3. Metal removal efficiency at the Lilly/Orphan Boy Mine.

ACTIVITY III, PROJECT 8: UNDERGROUND MINE SOURCE CONTROL

Project Overview

A significant environmental problem at abandoned underground mines occurs when the influx of water contacts sulfide ores and forms acid and metal-laden mine discharge. The Underground Mine Source Control Project demonstrated that grout materials can be used to reduce and/or eliminate the influx of water into the underground mine system by forming an impervious barrier that results in reduced, long-term environmental impacts of the abandoned mine.

Technology Description

Groundwater flow is the movement of water through fractures, faults, or intergranular spaces in the earth. Some of the fractures are naturally occurring; others were the result of blasting during mining.
For this demonstration, a closed-cell, expandable polyurethane grout was injected into the fracture/fault system that intercepted the underground mine workings. The demonstration consists of three phases: 1) extensive site characterization; 2) source control material identification and testing; and 3) source control material emplacement.

Phase One, completed in 1999, consisted of site selection and characterization including hydrogeological, geological, geochemical, and geophysical information gathering directly related to the mine and its operational history. The Miller Mine near Townsend, Montana, was selected for the demonstration because the underground workings were accessible, had point-source inflows to the underground workings, the inflow was slightly acidic and laden with heavy metals, and could potentially be controlled using a source control technology.

Phase Two encompassed source control material testing according to ASTM methods for acid resistiveness, shear strength, plasticity, compressive strength, compatibility, and viscosity. The source control grout material selected for injection was Hydro Active Combi Grout, a closed-celled, expandable polyurethane grout manufactured by de neef Construction Chemicals, Inc. This material offered the following advantages: greater retention of plasticity; less deterioration due to the acidic conditions and rock movement; and better rheological characteristics.

Phase Three, the field emplacement was performed during two periods. The first technology emplacement, completed in October 1999, used a core drill to drill and grout greater than 70-foot core holes that extended over the underground mine workings and intercepted the Miller Mine reverse fault system. A second grout injection was completed in April 2001 using short holes drilled using a jackleg drill. Workers drilled approximately 400 feet of holes and grouted using about 68 gallons of grout.

As a result of the October 1999 grout emplacement, the first year monitoring results indicated that flow into the underground mine was reduced from approximately 11 to almost 1 to 1.2 gpm in the W1 drift, the drift with acidic water and only drift grouted, see Figure 4. The average flow from the Miller Mine portal was reduced by approximately 76% after all grout was emplaced, see Figure 5. However, improvements in the metals loading at the Miller Mine portal were recognized; the main metals with reduced loading were iron, nickel, manganese, and zinc. Other metals were near the instrument detection limits.

Status

The final report for the project is being completed in 2004 and will be available on the MWTP website when it is finalized.

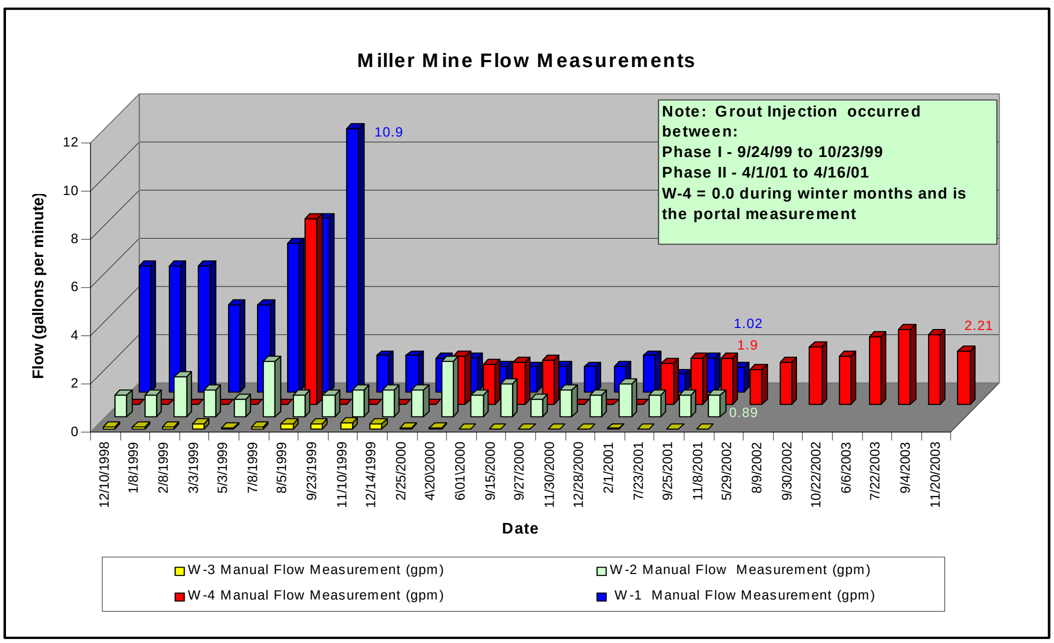
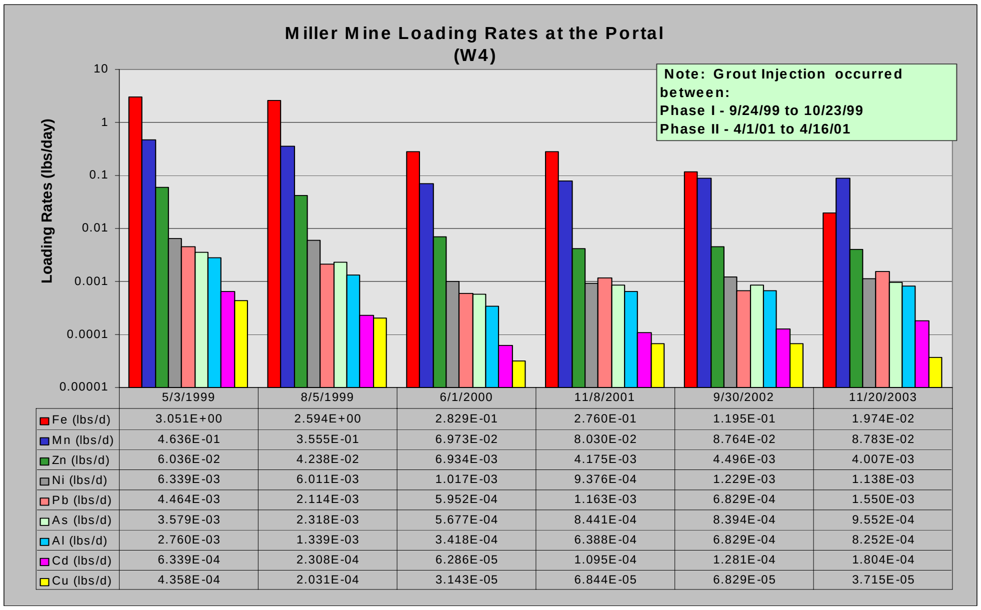


Figure 4. Manual flow measurements for the Miller Mine project. W1, W2, and W3 are inflow, and W4 measures the total outflow from the mine.



	5/3/1999	8/5/1999	6/1/2000	11/8/2001	9/30/2002	11/20/2003
Fe (lbs/d)	3.051E+00	2.594E+00	2.829E-01	2.760E-01	1.195E-01	1.974E-02
Mn (lbs/d)	4.636E-01	3.555E-01	6.973E-02	8.030E-02	8.764E-02	8.783E-02
Zn (lbs/d)	6.036E-02	4.238E-02	6.934E-03	4.175E-03	4.496E-03	4.007E-03
Ni (lbs/d)	6.339E-03	6.011E-03	1.017E-03	9.376E-04	1.229E-03	1.138E-03
Pb (lbs/d)	4.464E-03	2.114E-03	5.952E-04	1.163E-03	6.829E-04	1.550E-03
As (lbs/d)	3.579E-03	2.318E-03	5.677E-04	8.441E-04	8.394E-04	9.552E-04
Al (lbs/d)	2.760E-03	1.339E-03	3.418E-04	6.388E-04	6.829E-04	8.252E-04
Cd (lbs/d)	6.339E-04	2.308E-04	6.286E-05	1.095E-04	1.281E-04	1.804E-04
Cu (lbs/d)	4.358E-04	2.031E-04	3.143E-05	6.844E-05	6.829E-05	3.715E-05

Figure 5. Miller Mine portal heavy metals loading rates before and after the grout emplacement.

ACTIVITY III, PROJECT 15: TAILINGS SOURCE CONTROL

Project Overview

Processing metallic ores to extract the valuable minerals leaves remnant material behind called tailings. In the case of sulfide mineral-bearing ores, process tailings often contain large quantities of sulfide minerals that do not meet the economic criteria for extraction. These remnant sulfide minerals are usually pyrites and nonextracted ore minerals. The exposure of these minerals to air and water often leads to detrimental environmental conditions such as increased sedimentation in surface waters due to runoff events, increased wind borne particulate transport, generation of acid mine drainage, and increased metals loading in surface and groundwaters.

Technology Description

The objective of this demonstration was to identify potential source control materials and apply one or more of them at a selected site. The demonstration consists of two phases: 1) site characterization and materials testing; and 2) materials emplacement and long-term monitoring and evaluation.

Phase one consisted of the site characterization studies, including hydrogeological, geological, and geochemical information directly related to the tailings impoundment. The materials testing and development involved testing, evaluation, and formulation of source control materials for application at the selected site.

Phase two encompassed the application of three selected source control materials at the demonstration site and an evaluation of the material application and feasibility. Long-term evaluation of the materials included air borne particulate testing, moisture profiles generated from reflectometers, in situ permeability tests (using Guelph Permeameters), ex situ permeability tests, and freeze/thaw testing (flexible wall permeameter).

Status

The Mammoth Tailings site located adjacent to the historic mining town of Mammoth, Montana (see Figure 6) was the project site selected. Material testing was completed during the first quarter of 2000. Three source control materials were applied at the site during the summer of 2001. These materials included two, polymeric cementitious grouts that incorporate the tailings material as a filler material (IESCRETE and Krystal Bond) and a spray-applied, modified polyurea chemical grout. A year of volumetric soil moisture testing and material evaluation was completed by the end of calendar year 2002. The final report with the results of the monitoring and material evaluation will be finalized in the first part of calendar year 2004.

Figure 6. Mammoth Mine Tailings site showing the three applied technologies. Left to right, modified polyurea, ISCRETE, and Krystal Bond cementaceous grouts.

ACTIVITY III, PROJECT 16: INTEGRATED PASSIVE BIOLOGICAL TREATMENT PROCESS DEMONSTRATION

Project Overview

The Integrated Passive Biological Treatment Process project will demonstrate a technology consisting of a series of biological processes for the complete mitigation of acid mine drainage (AMD). As the first part of this project, the technology was tested successfully at bench-scale. Now, demonstration of the process is being attempted in the field at a remote, abandoned mine, the Surething Mine, near Elliston, Montana. At this site, the bacteria live within a series of reactors constructed in the ground outside an AMD discharging mine (see Figure 7). Both anaerobic and aerobic bacteria are being used to mitigate AMD. Toxic dissolved metallic and anionic constituents are being removed, and the pH of the final process effluent is near neutral.

Technology Description

The majority of the treatment is conducted in anaerobic, sulfate-reducing bacteria (SRB) bioreactors. When provided with sulfate (present in the AMD) and a carbon source (provided in the pit reactor is a 50% cow manure and 50% walnut shell mixture), SRB produce bicarbonate and hydrogen sulfide gas. The bicarbonate neutralizes the pH of the AMD while the hydrogen sulfide gas reacts with the dissolved metal ions to precipitate them as metal sulfides.

Additional treatment is conducted in an aerobic, manganese-oxidizing bacteria (MOB), bioreactor that was designed to have an indigenous bacteria population self establish as a biofilm on the limestone cobble. Required micronutrients are to be derived from the organic matter in the water carried over from the upstream SRB Reactors.

Status

The field demonstration has been monitored since September 2001. The data generally demonstrates a significant decrease in metals concentrations (see Figure 8), with the exception of manganese.

Shortly after the system started operation, over 95% of the influent manganese was removed. Removal was less over the winter months and rose again in the spring. Thereafter, the manganese removals were drastically lower, indicating that a population of manganese-oxidizing bacteria was having problems developing. It was determined that the original passive aeration configuration was not sufficient to treat the amount of sulfide being carried over from the upstream SRB Reactors. Over the summer, a new aeration system was installed but was not fully effective. Additional process changes will be implemented during the next operational season to make the system favorable to MOB growth.

Figure 7. Integrated Passive Biological Treatment Process Demonstration Site.

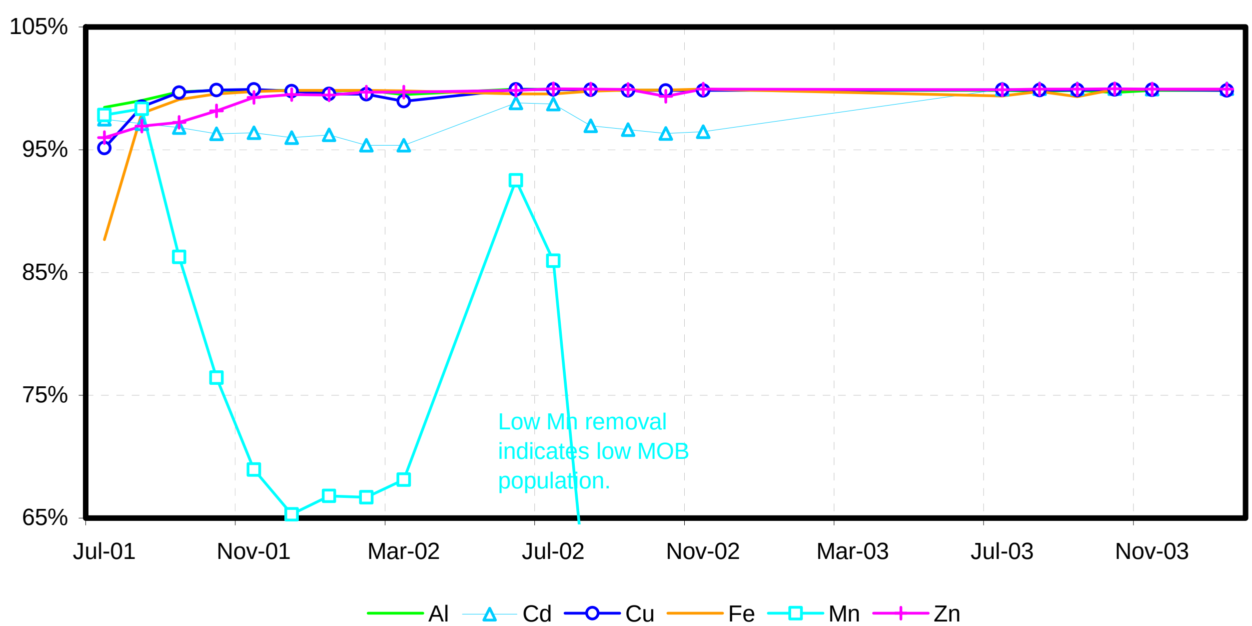


Figure 8. Metal removal efficiency for the Integrated Passive Biological System.

ACTIVITY III, PROJECT 21: INTEGRATED PROCESS FOR TREATMENT OF BERKELEY PIT WATER

Project Overview

The objective of this project is to develop integrated, optimized treatment systems for processing Berkeley Pit water. The Berkeley Pit is an inactive open-pit copper mine located in Butte, Montana. Currently containing approximately 37 billion gallons of acidic, metals-laden water, the Berkeley Pit is filling at a rate of approximately 3 million gallons per day and is a good example of acid rock drainage.

Two optimized flowsheets will be developed. One flowsheet is to be oriented toward minimizing the overall cost of water treatment to meet discharge requirements; this will include not only water treatment equipment but also sludge handling/management. The other flowsheet is to be oriented toward also meeting discharge requirements, but includes the recovery of products from the water (e.g., copper, metal sulfates, etc.) to potentially offset treatment costs and result in overall better economics.

Technology Description

The project evaluated proven technologies (e.g., precipitation, ion exchange, cementation, solvent extraction, electrolysis, filtration options, etc.) as well as technologies with credible pilot-scale supporting data. Technologies with only laboratory testing history were not included. The goal is to assemble the sequence of unit operations resulting in the most attractive overall economics.

Status

In FY03, work progressed on the project final report, focused primarily on the product recovery flowsheet. Results indicate that discharge of sludge from treatment to the Berkeley Pit, using a high-density sludge lime treatment process, is the most economically favorable water treatment approach. Efforts expended on metals recovery indicate that most of the metals present cannot be profitably recovered due to their low value and dilute concentrations. Copper can be recovered profitably using the existing cementation process, recovery as a sulfide, or electrolytically by the EMEW cell technology. Upgrading the sulfide to a sulfate (e.g., via sulfation roasting) or oxide may improve the economics of that option. It appears that no other metals are economically recoverable. If zinc can be cheaply upgraded to a form other than sulfide, it may also be economically recoverable, but probably not at current zinc prices. Fiscal 2004 plans include completing the project final report.

ACTIVITY III, PROJECT 24 IMPROVEMENTS IN ENGINEERED BIOREMEDIATION OF ACID MINE DRAINAGE

Project Overview

Investigations conducted for this project focused on the improvements of engineered features and the predictability of a passive technology that could be used for remediation of thousands of abandoned mine sites existing in the Western United States. This passive remedial technology, a sulfate-reducing bacteria (SRB) bioreactor, takes advantage of the ability of SRB that, if supplied with a source of organic carbon, can increase pH and alkalinity of the water and immobilize metals by precipitating them as metal sulfides or hydroxides.

Technology Description

The remoteness of acid mine drainage (AMD) sites, their abundance, and related economical aspects require that the design of an SRB bioreactor is simple and relatively inexpensive and that the bioreactor is capable of treating any AMD flow rate. Therefore, bioreactors need to be prefabricated and designed to a size that allows for transportation using backcountry roads in mountain regions. These conditions require that the design of the bioreactor be modular so the treatment system can be assembled at the mine site and consists of the number of modules as required by the AMD flow rate and the metals load. This modular configuration of the SRB treatment system needs to support the prime functional aspects of a bioreactor such as high permeability, ample supply of organic carbon, ability to maintain anaerobic conditions, capacity to accumulate precipitated metals, and means for their periodical removal, if needed. In addition, the configuration of the bioreactor should allow for an easy replacement of organic carbon, if needed. Obviously, the design and sizing of such a treatment system needs to be streamlined and performance of the system predictable. Therefore, the two main objectives of the project were:

- developing an SRB bioreactor whose reactive material (organic matter) would not be prone to plugging and, if exhausted, would be easy to replace; and
- quantifying reactivity of organic material and developing a simulator that would facilitate optimization of the design parameters and the size of the SRB treatment system.

These project objectives were achieved through the implementation of the following work tasks:

- selecting the medium with organic carbon;
- designing an organic carbon replaceable cartridge (RC); and
- developing a computer simulator to design and size an SRB treatment system for the given dissolved metal concentration in AMD and its flow rate.

Status

The project was completed, and the results are reported below.

Selection of the medium with organic carbon was accomplished through a literature search. All information gathered during the literature search is contained in the database assembled using Microsoft (MS) Access™. The report of this investigation (MSE Technology Applications, Inc., report MWTP-188) includes the list and references regarding substrate mixture components used in SRB treatment systems and their effectiveness. The report identified 36 organic substrates and lists the main conditions that need to be considered for selecting the most appropriate organic medium. Based on the results of this search, a new organic substrate, a mix of walnut shells and cow manure (W/M), was developed and selected for the project. Some advantages of using this mix are listed below.

- Cow manure is an easily biodegradable organic matter that ensures a quick startup of the bioreactor.
- Cow manure includes nitrogen needed by other microorganisms for the initial decomposition of manure. Moreover, the nitrogen is in the form of ammonium that is easier for microorganisms to use than nitrates.
- Walnut shells are more recalcitrant to biodegradation, thus, supporting good long-term operation of a bioreactor.
- Walnut shells provide a solid matrix structure because individual shells actually rest on each other. This structure prevents time-driven compaction (settling), thus, works toward preservation of the initial permeability of the medium.
- Walnut shells contain a high percentage (56%) of total organic carbon (TOC). The TOC of manure is lower and varies depending on the manure source, from 8% to 20%.

- The sustainable hydraulic conductivity of the mixture is 0.01 centimeter per second (cm/s) or higher, based on the results of experiments conducted for the project.

The investigations leading to the recommended design of the RC included testing of the W/M organic medium for its permeability and sulfate reduction rates (SRR).

The permeability tests were conducted in two configurations: 1) an upward vertical flow and 2) a horizontal flow. Results of these tests indicate that the long-term permeability of this medium is significantly higher for flow in a horizontal plane. This phenomenon is attributed to the deformation of the W/M organic medium in which the finest particles are mobilized by the flowing water and migrate downward by gravity to settle at a certain level, usually at the bottom of the container, blocking the flow. In the case of a horizontal configuration, the migrating particles also settle in the bottom of the container; however, they do not block the entry of water that flows above them as it is fed laterally. The experiments conducted showed that for a horizontal flow configuration the sustainable hydraulic conductivity (K) of the mixture is 0.01 cm/s or higher. Generally, the hydraulic conductivity value for the 50% to 50% W/M organic medium mix was 1 order of magnitude smaller than the K value for the 80% to 20% W/M mix.

The laboratory work to determine SRR included six experiments conducted for two synthetic compositions of AMD at three temperatures [i.e., 44 °F (6.7 °C), 58 °F (14.5 °C), and 77 °F (25 °C)]. The two synthetic AMDs, referred to in this document as medium and strong, had pH values of 4.2 and 2.6, respectively. The SRR values ranged from 0.17 moles per day per cubic meter [$mol/(d*m^3)$] to 0.79 $mol/(d*m^3)$ with the overall mean value of 0.40 $mol/(d*m^3)$. Sulfate reduction rate values in these experiments seemed to be independent of the strength of the influent and the temperature at which the experiments were conducted.

The recommended design of the RC (Figure 9) uses a commercially available cylindrical or cuboidal plastic tank most often constructed of high-density polyethylene (HDPE) or polypropylene. Such a tank needs to be equipped with necessary features to accommodate the W/M organic medium and serve as one SRB RC. These modifications will be made in a machine shop, and the tank will then be transported to a mine site. The tank will be installed either aboveground or belowground at the mine site, as required by the site conditions. An appropriate piping system will convey the AMD into the RC.

The 5-gallon bags with W/M 0.8/0.2 organic medium shown in this figure are made of plastic netting that is commonly used by grocery shops for prepacked fruits. Each bag has a loop in its top portion to facilitate the placement and the removal of the bags from the RC using a rod with a hook. A plastic tarp (not shown in the picture) placed on the top of the bags creates anaerobic conditions. The cost of production and installation (excluding transportation to the site) of such an RC housed in a 2,500-gallon HDPE tank is approximately $8,100. The cost may vary depending on local supply and labor rates applicable at the given location.

The number of RCs and the system configuration is determined through modeling conducted using the bioreactor economics, size and time of operation (*BEST*) computer simulator developed for this project. This simulator is a spreadsheet-based model that is used in conjunction with a public domain computer software package, PHREEQCI geochemical modeling program. While PHREEQCI calculates geochemical equilibrium for the advective-reactive transport of AMD through the bioreactor, the spreadsheet portion of the simulator handles issues of AMD flow rate, size of the bioreactor, its operational time, and its economics.

In general, the *BEST* simulation process is based on the chemical composition of the AMD and its flow rate; TOC content in the organic matter; cost of material and production of a typical RC; the SRR of the organic matter used in the treatment system; and the discount rate (DR) and operation and maintenance (O&M) cost for calculation of the net present value (NPV). The *BEST* simulator was developed and formulated so that it can be operated by a user with minimum modeling experience.

The *BEST* simulator, saved as a Microsoft Excel™ workbook, consists of an input/output (I-O) worksheet and 14 additional worksheets, most of them linked together and working in the "background" of the I-O worksheet. The I-O worksheet allows for entering the majority of input data and shows the most important results.

Most worksheets are linked together, i.e., any change of input data causes appropriate changes of the results calculated by the respective worksheet. However, the PHREEQCI model and its data input file (one of the "background" worksheets) are not automatically linked with the rest of the worksheets, thus, required changes need to be made manually. Two flow charts explained the navigation between these "background" worksheets.

The time of operation calculated by BEST is based on the available carbon present in the W/M organic medium divided by the safety factor of 4. This safety factor is used because the investigations conducted for the project did not focus on confirmation of whether the organic carbon present in the medium is entirely available for the SRB.

An example simulation provided in the final report considers AMD flowing at 1 gallon per minute (gpm) and laden with 17.78 milligrams per liter (mg/L), 6.12 mg/L, 0.08 mg/L, and 40.4 mg/L of zinc (Zn), copper (Cu), cadmium (Cd), and aluminum (Al), respectively. An SRB treatment system to remove Zn, Cu, and Cd as sulfides would require three RCs and the capital cost of $24,244. The NPV is $37,768 based on a DR of 3.2%, O&M at $1,000/year, and the operational time of 18 years.

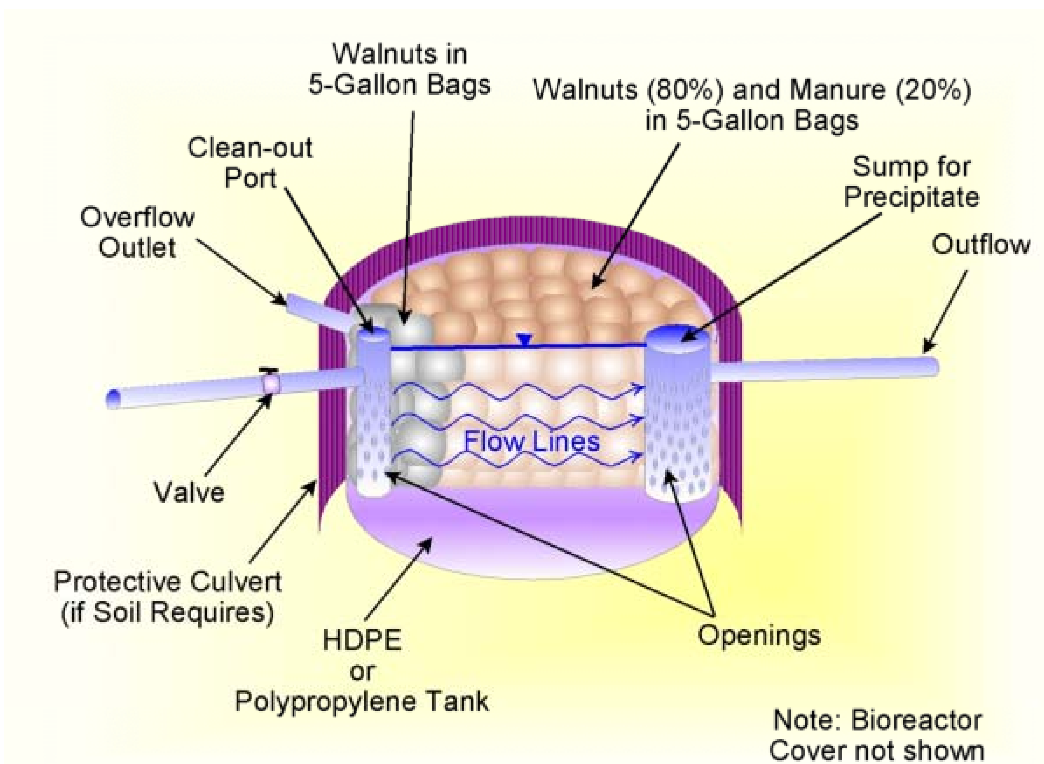


Figure 9. Sulfate-reducing bacteria replaceable cartridge system

ACTIVITY III, PROJECT 26 PREVENTION OF ACID MINE DRAINAGE GENERATION FROM OPEN-PIT MINE HIGHWALLS

Project Overview

Exposed, open-pit mine highwalls contribute significantly to the production of acid mine drainage (AMD) and can be problematic upon closure of an operating mine. Four innovative technologies were evaluated under the Mine Waste Technology Program (MWTP) *Prevention of AMD Generation from Open-Pit Highwalls Demonstration Project*. The objective of the field demonstration was to evaluate technologies for their ability to decrease or eliminate acid generation from treated areas of the highwall, compared to untreated (control) highwall areas.

Technology Description

Generation of AMD from open-pit mine highwalls has been addressed in a limited manner, and little information is available on the subject. However, highwall generated AMD will continue to be produced for indefinite periods of time as weathering occurs and the flushing action of atmospheric precipitation and/or groundwater infiltration through the highwall takes place.

The main purpose of this project was to research technologies applicable to controlling or eliminating AMD generated from open-pit mine highwalls and then apply and monitor the potential technologies under actual field conditions. For this demonstration, four technologies having potential to passivate AMD from a highwall were selected for field application. The application methods required for each technology varied along with the application time and the materials.

The demonstration consists of three phases: 1) extensive site characterization and gathering background information; 2) technology identification and field application; and 3) long-term field monitoring and laboratory testing for confirmation of field results.

Site characterization in Phase I included core drilling the highwall to determine geology, hydrogeology, and extent and depth of acid generation (i.e. geochemical analysis), and performing background sampling at all of the sampling ports placed on the highwall. Phase II involved selecting a site [the Golden Sunlight Mine (GSM) near Whitehall, Montana], the highwall technologies, and applying the technologies in the field. The four technologies that were spray-applied to the highwall included: furfuryl alcohol resin sealant (FARS), Eco Bond™, a magnesium oxide (MgO) and a potassium permanganate (KP) treatment.

The third phase of the project involved monitoring the technologies using ASTM D5744-96, Accelerated Weathering of Solid Materials using Modified Humidity Cells, residual wall rinse sampling at the treated highwall plots, and microscopy.

Monitoring results indicated that all treatment technologies reduced the amount of AMD generated on the highwall. Each technology performed differently based on metals removal/reduction. When compared to the background plot during the 41 weeks of humidity cell testing, the results indicated that the overall effectiveness of the technologies from least to most effective was FARS, Eco Bond™, KP, and MgO. For the mine wall rinse sampling, the residual wall rinse results indicated that the overall effectiveness of the technologies from least to most effective was Eco Bond™, MgO, KP, and FARS. Over the course of the project, deterioration of the highwall led to fewer available mine wall rinse sampling stations and less data for evaluation of the plots. The pH of the highwall at each plot initially started at greater than pH 10 except for FARS, which started at 4.5. The pH at the last sampling event shows that the pH at each plot has decreased over time except FARS, and the wall rinseate results for iron indicated how each technology affected the metals loading from the highwall.

Figure 10 shows pH results from the highwall residual wash sampling. The GSM (background) results are compared to the FARS, Eco Bond (MT^2), MgO, and KP technologies.

Figure 11 shows the iron totals metals loading results from the highwall residual wash sampling. Other metals were observed in the same manner and are included in the final report.

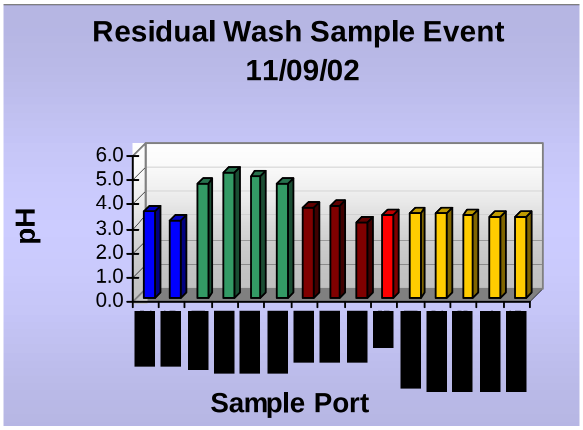


Figure 10. pH results from the highwall residual wash sampling.

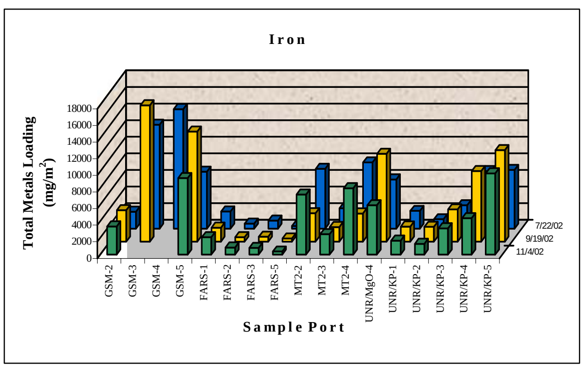


Figure 11. Iron totals metals loading results from the highwall residual wash sampling.

Status

The field demonstration was performed at GSM, a subsidiary of Placer Dome, an operating gold mine located near Whitehall, Montana. The ore body at GSM is sulfidic, and the exposed highwall provides an AMD source.
Phase one, site characterization, was completed in September 2001.

Phase two, which included technology selection, was completed by May 2001. Placement of the technologies was performed between October and December 2001.

The technologies were evaluated in 2002 using a residual wall rinse sampling method and a modified humidity cell testing method. The humidity cell testing was extended to 41 weeks and was completed in FY03. The final report will be completed in FY04.

ACTIVITY III, PROJECT 29 REMEDIATION TECHNOLOGY EVALUATION AT THE GILT EDGE MINE

Project Overview

The objective of this project is to generate performance and cost data for promising new technologies for preventing the oxidation of sulfide waste rock, which may be applicable to many mine waste sites. The new technologies will be compared to the presumptive remedy of lime treatment as well as to controls in which no treatment is performed. The technology demonstration was performed at the Gilt Edge Mine, a 270-acre, open-pit cyanide heap leach gold mine located about 5 miles southeast of Lead, South Dakota. The immediate area was the site of sporadic mining activity for over 100 years. The Gilt Edge Mine was operated by

Brohm Mining Corporation, a wholly owned subsidiary of Dakota Mining Cooperation from February 1986 until July 1999. Brohm's activities included developing several open pits, crushing and placing the ore on a heap leach pad for gold leaching by cyanidation, and Merrill-Crowe gold recovery in an on-site mill. In July 1999, the mine's owners (Dakota Mining Corporation) declared bankruptcy, resulting in the Gilt Edge site being returned to the State of South Dakota for management. After incurring significant costs for water treatment to ensure no discharge of acidic mine water to the environment occurred, the State of South Dakota requested that EPA Region VIII take over the site and list it on the National Priorities List (NPL) as a Superfund site. The Gilt Edge Mine site presents an opportunity to evaluate emerging acid mine drainage (AMD)-treatment technologies while gathering data leading to a Record of Decision (ROD) for the site.

This project was a collaboration between EPA Region VIII and the EPA Mine Waste Technology Program (MWTP). The objective of Region VIII was to conduct a treatability study as part of the remedial investigation/feasibility study process for the site—providing data to help make decisions supporting the ROD for the site. The technical and economic information will be summarized in a final report to assist Region 8.

The project involved constructing test cells that were loaded with sulfide-bearing waste rock from the Gilt Edge Mine site. EPA Region VIII (or its contractors), assisted by the U.S. Bureau of Reclamation designed and constructed the test cells, as well as loaded the waste rock into the cells. Three technology providers installed their respective technology for reducing AMD generated by the waste rock. The project occurred west of the Anchor Hill Pit at the Gilt Edge Mine. The test cells received ambient precipitation, and an irrigation system applied additional simulated precipitation to the test cells. A system for managing and sampling leachate quality designed by EPA Region VIII was integrated into the cell design. Twelve test cells were planned. Two cells were dedicated to each of the three technologies to show performance repeatability. Three control cells containing only waste rock (with no additional treatment) and three cells representing the presumptive remedy of blending lime with the waste rock were also constructed. The performance of the installed technologies was judged primarily by comparing leachate water quality from the installed technology cells with that of the control and presumptive remedy (lime treatment) cells. The test cells were constructed and loaded in September 2000.

Technology Description

The three technologies demonstrated were:

- Silica microencapsulation [Klean Earth Environmental Company (KEECO)];
- Envirobond [Metals Treatment Technologies (MTT)]; and
- Passivation technology [Mackay School of Mines, University of Nevada, Reno (UNR)].

KEECO has developed a treatment technology for treating and preventing metals-contaminated waters, soils, and possibly sulfidic waste rock called silica microencapsulation (SME). This technology encapsulates metals in an impervious microscopic silica matrix (essentially locking them up in very small sand-like particles) that prevents the metals from leaching and migrating. Its chemical components react when introduced to water, creating an initial pH adjustment and electrokinetic reaction. The electrokinetic reaction serves to facilitate electrokinetic transport of metal particles toward the reactive components of the SME product, enhancing its efficiency. Metal hydroxyl formation follows; next, silica encapsulation of the metals occurs, forming a dense, stable coating. Contrary to conventional treatment process where sludges typically degrade over time, the SME silica matrix appears to continue to strengthen and tighten, providing for long-term isolation of contaminants from the environment. Silica microencapsulation has been applied to wastewater, sediment, sludge, soil, mine tailings, and other complex media but has never been applied and tested directly on sulfidic mine waste rock materials.

The Envirobond (Metals Treatment Technologies) technology is similar to the KEECO technology except that it involves phosphate stabilization chemistry rather than silicates. The technology has been applied at mining sites, firing ranges, sediment removal sites, and others to produce a solid treatment material meeting Toxicity Characteristic Leaching Procedure criteria. The technology can be adapted for a variety of wastestreams and soil conditions.

Over the past few years, DuPont developed a novel coating method known as a passivation technology. Recently, the technology was donated to UNR for further development and commercialization. The passivation process essentially creates an inert layer on the sulfide phase by contacting the sulfide with a basic permanganate solution to produce an inert manganese-iron oxide layer. This layer prevents contact with atmospheric oxygen during weathering of the sulfide rock, thus, preventing sulfuric acid generation. Another critical element of the process is the addition of trace amounts of magnesium oxide during pH adjustment. Magnesium oxide addition enhances the coating strength.

Status

The treatment cells (Figure 12) were loaded and treated by the technology vendors in November 2000. Treatment monitoring started May 2001 and continued through December 2002.

Data analysis from the sampled leachate included comparing parameters of each leachate to the South Dakota Water Quality Criteria (SDWC) applicable to the Gilt Edge Mine. Two indicators that reflect overall effectiveness are the total dissolved solids (TDS) concentrations and the pH trends of each technology. Figure 13 shows the TDS trends. The presumptive remedy cells of 4, 7, and 12 all reached the SDWC of 2500 milligrams per liter (mg/L). The UNR cell 3 trend was very close to the 2500 mg/L limit. Figure 14 shows the pH trend for the technologies. The SDWC pH range is 6.5 to 8.8. The MT^2 cells 5 and 11 trends were within this range for the duration of the test, while the UNR cell 3 was in the range for the majority of the test.

MSE Technology Applications, Inc., is currently evaluating sampling and cost data to evaluate the treatment technologies. A final report will be written and should be finalized in FY04.

Figure 12. Treatment cells.

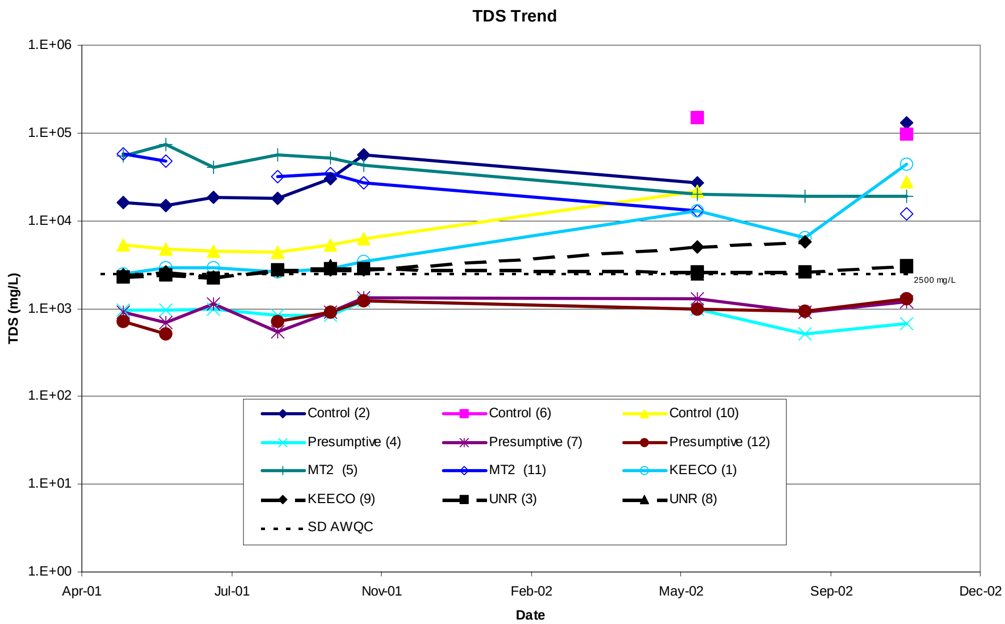


Figure 13. Total dissolved solids trends.

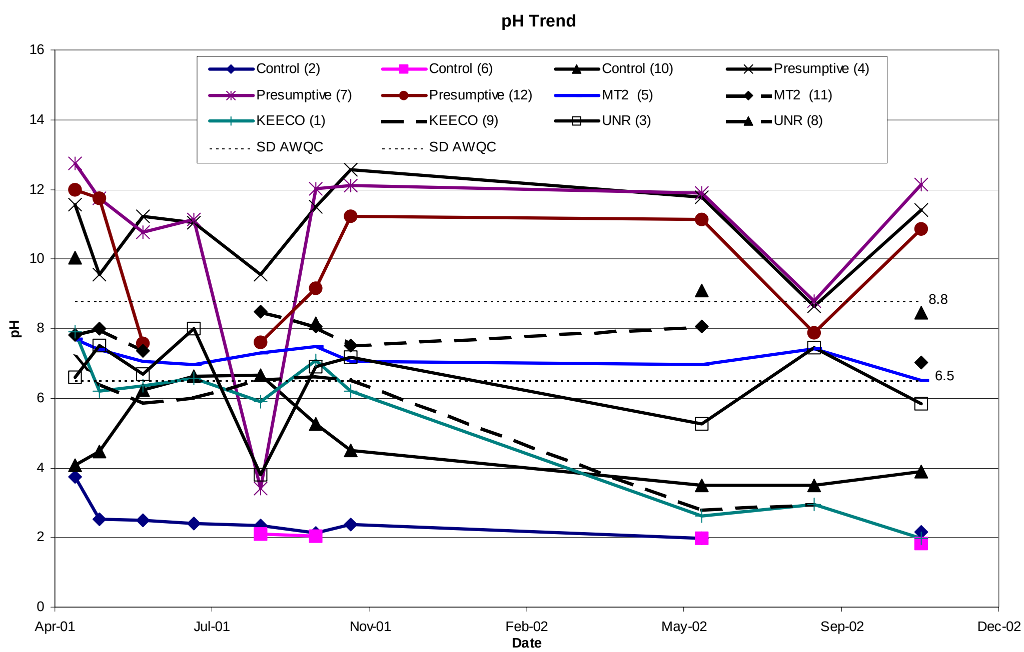


Figure 14. pH trend.

ACTIVITY III, PROJECT 30 ACIDIC/HEAVY METAL-TOLERANT PLANT CULTIVARS DEMONSTRATION, ANACONDA SMELTER SUPERFUND SITE

Project Overview

Presently, grass, forb, and shrub species commercially available for reclaiming acidic/heavy metals-contaminated (A/M) soils often come from outside the Northern Rocky Mountain region. These cultivated varieties may not tolerate the climatic-edaphic stresses (in addition to A/M stresses) as well as would A/M ecotypes indigenous to the region. Over the past several years, plant populations exhibiting A/M tolerance potential have been collected from the Anaconda Smelter Superfund Site and evaluated in laboratory, greenhouse, and preliminary field trial studies. The results indicate that self-sustaining plant communities comprised of native A/M tolerant ecotypes are possible. Thus, the goal of this project is to formally compare the performance of local seed mixes against comparable mixes now commercially available. If the local ecotypes (of the given grass/forb species) are indeed best performing, they would be made available for numerous full-scale reclamation of the hardrock mine/mill/smelter sites in the region.

Technology Description

The team comprised of the Deer Lodge Valley Conservation District (DLVCD), USDA/Bridger Plant Materials Center (BPMC), and MSE Technology Applications, Inc., selected and evaluated the most promising grass/forb accessions at test sites in the Anaconda area over the 2002–2004 growing seasons. Shrub species were evaluated at another site that is not formally part of the Mine Waste Technology Program funded study.

The initial (FY02) study design used four grass/forb mixtures from southwestern Montana and taxonomically similar mixtures of commercially available cultivars. Four replicates of each mixture were planted (in late fall 2001) at both the Stucky Ridge and Mill Creek test sites. However, a hypothesized combination of drought, soil acidity, and plant available metals levels precluded effective seedling growth and establishment of any of the mixtures at both sites during the 2002 field season.

Subsequently, regulatory personnel from the State of Montana and EPA agreed to pretreatment (i.e., liming and fertilizing) of the soils before planting. The study's goal was also modified to allow comparison of growth performance of species-specific accessions in the field (versus greenhouse), when grown either by themselves or in defined mixtures of various species.

The laboratory and field data gathered during the remaining seasons will be statistically analyzed to determine whether any of the local seed mixes outperforms their commercial counterparts. Results to date are summarized in Table 2.

Status

The following activities continued in FY03: collection and laboratory analysis of plant and soil samples from the Anaconda area; field evaluations of plant performance; and production of seeds (at BPMC) from the most promising grass/forb accessions. The test site was relocated to the north side of Stucky Ridge in the fall of 2002. The upper 6 inches of soil were amended with lime kiln waste (approximately 22 tons per acre) in mid-November; about 500 pounds per acre of NPK fertilizer was tilled into the soils in April 2003. The grass, forb, and grass/forb seed treatments were planted in mid-May 2003; rooting zone soil samples were then collected for acid extractable metal levels and saturated paste pH. The laboratory results are shown in Table 2 and indicate that phytoxic levels of copper may exist within the rooting zone.

Overall, seedling density decreased between late June and late August for all three treatment types. The record high temperatures and low precipitation in July and August seem to be the dominant factors affecting the decline.

None of the local grass accessions had significantly greater densities than for the nonlocal accessions. With the exception of a nonlocal accession of winterfat, the forb/subshrub accessions exhibited poor emergence and consequently poor seedling densities. This effect may be due to an insufficient period of cold-moist stratification (i.e., it would have been better for the seeds to have over-wintered in the soil).

The seed mixtures consisting of commercially available nonlocal varieties had slightly higher seedling densities but were not significantly greater than those exhibited by the local accessions. The Waste Management Area seed mixtures that consisted of both introduced and native species performed as well as the upland seed mixtures that included only native species.

Table 2. Development of Acid/Metal Tolerant Cultivars Project: Baseline Soils Data Summary[a]

	Analytes[b]					
Treatment Type	**As**	**Cd**	**Cu**	**Pb**	**Zn**	**pH**
Grass accessions (only)	151±22	1.2±0.2	870±50	46±6	192±14	8.0±0.1
Forb accessions (only)	120±8	1.4±0.4	909±102	38±2	194±9	7.8±0.1
Grass/Forb mixtures	186±77	1.4±0.4	801±64	55±23	186±18	7.7±0.1

Notes: [a] For 0-6-inch (below ground surface) soils collected at the Moto-Cross site in late June 2003.
[b] Acid-extractable metals/metalloid (As) in mg/kg; 1:1 soil: water pH in standard units.
[c] □ values exceed the 250 to 500 mg/kg threshold of concern stated in the 2001 Quality Assurance Project Plan.

ACTIVITY III, PROJECT 33 MICROENCAPSULATION TO PREVENT ACID MINE DRAINAGE

Project Overview

This technology demonstration project was conducted on a cost share basis with the Minnesota Department of Natural Resources. The objectives were to evaluate the potential field application success in preventing acid mine drainage and to estimate requirements for field applications.

An unoxidized sulfidic rock material was tested with three application levels of two commercially available microencapsulation technologies: Klean Earth Environmental Company (KEECO) and Envirobond. They were evaluated in comparative laboratory studies using modified humidity cell operation.

Technology Description

Microencapsulation is the isolation of sulfide minerals by precipitating a chemical *coating* on unoxidized pyrite or where the material is reacted with an oxidizing agent to produce ferric ions.

The KEECO KB-SEA technology uses a soluble silica to produce an insoluble ferric silicate precipitate that encapsulates solid media particles. The materials become stabilized as this silica coating helps to control future acid generation.

The Envirobond EcoBond-ARD technology uses a soluble phosphate to form a ferric phosphate precipitate that prevents the leaching of metal contaminates by creating an impenetrable chemical bond.

Humidity cells containing three application rates (high, medium, and low) with duplicates for each along with control cells were tested and leached weekly.

Status

The control reactors had acid drainage with a pH >6 after 1 week and a pH of 3.3 at 60 weeks. Over the first 60 weeks of testing, the KB-SEA treatment was successful in preventing acid drainage; however, it must be noted that initially very high pHs were generated in comparison to the controls (see Figure 15).

The EcoBond treatment delayed the onset of acidification but was not successful in preventing acid drainage. Project testing of the EcoBond cells was discontinued at 60 weeks with one set of the EcoBond-ARD duplicate cells being sent to the technology provider for reapplication and continued leaching.

In 2003, the humidity cell phase for the Mine Waste Technology Program was completed, and a microscopic investigation of the test materials was initiated. The purpose of this work is to evaluate the formation of the actual microencapsulation layers along with trying to determine any failure mechanisms of the microencapsulation layer. Both treated, unleached material as well as the spent humidity cell material for each technology will be studied during FY04.

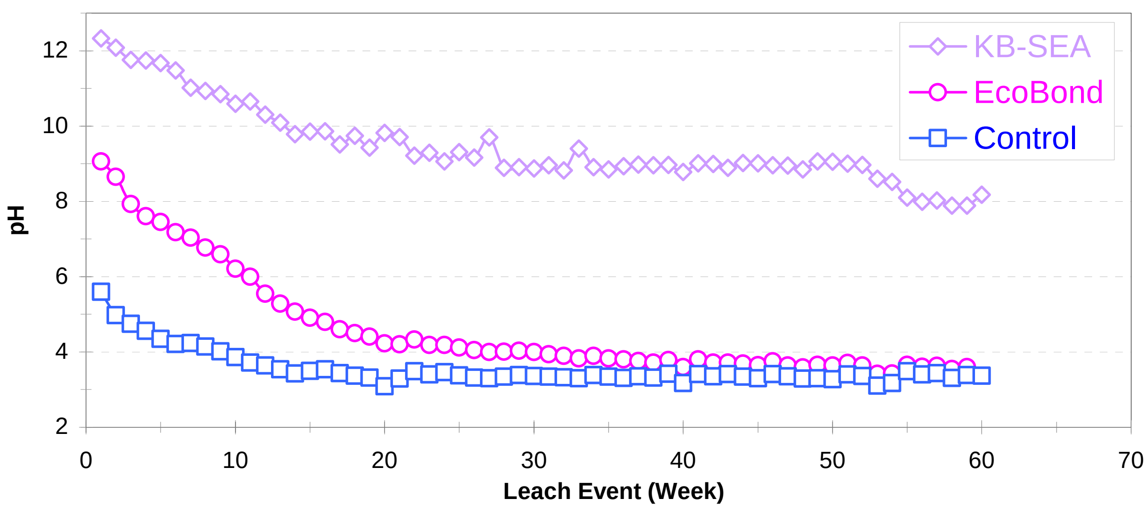


Figure 15. Microencapsulation humidity cell testing.

ACTIVITY III, PROJECT 34 BIOREMEDIATION OF PIT LAKES (GILT EDGE MINE)

Project Overview

This project is being conducted at the Gilt Edge Mine Superfund site near Deadwood, South Dakota. The project is a collaboration between the Mine Waste Technology Program and the U.S. Environmental Protection Agency's (EPA) Region VIII Superfund office. MWTP is taking the prime role in this project with support from EPA Region VIII. EPA Region VIII's interest is to conduct a treatability study as part of the site Remedial Investigation/Feasibility Study (RI/FS) process, while MWTP's interest is to develop data applicable to other similar sites. An in situ treatment of the Anchor Hill Pit, an open pit at the Gilt Edge site containing approximately 70 million gallons of acidic water containing high levels of metals, sulfate, and nitrate, is being performed. The treatment consisted of an initial neutralization step, followed by a biological treatment to further improve water quality and create a long-term, stable system. After the two-step treatment, the project entered a monitoring mode where the pit lake was physically and chemically characterized on a quarterly basis for several years. The purpose was to see how well the treatments work and how stable the pit lake water becomes, e.g., if metal sulfides are produced, does the system reoxidize and remobilize those metals

Technology Description

After initial chemical/physical characterization of the pit lake, the neutralization step was implemented by Shepherd-Miller, Inc. (SMI) of Fort Collins, Colorado, under subcontract to MSE Technology Applications, Inc. SMI used a Neutra-Mill fed with lime (CaO). The Neutra-Mill is simply a floating platform containing an apparatus to mix a reagent in with the water it is floating on. The Neutra-Mill was developed by Earth Systems, Pty. of Australia; SMI holds the U.S. license to apply the technology. Neutralization occurred between March and May 2001.

After neutralization, the pit was allowed to sit undisturbed for several weeks to allow precipitated solids to settle and the system to stabilize. After stabilization, the pit lake was once again characterized. Following this, in late May 2001, material consisting of methanol, molasses, and phosphoric acid was added to the pit lake. This process has been patented by Green World Science, Inc., of Boise, Idaho. The purpose of the organic carbon addition is to produce reducing conditions in the water and stimulate the activity of indigenous bacteria. This should have the effect of reducing or eliminating nitrate/nitrite and selenium, and polishing toxic metals concentrations to very low levels by precipitating them as sulfides (produced by reducing some sulfate to sulfide by sulfate-reducing bacteria activity), as well as adding bicarbonate alkalinity to the water to provide buffering capacity.

Status

Project accomplishments in FY03 included continuation of monitoring the pit water chemistry via obtaining analytical samples regularly as well as vertical profiles of physical measurements. Results were very encouraging, with completion of denitrification and initiation of sulfate reduction during FY03. Late in FY02, the pit received additional treatments including a pH increase to neutral (from approximately 5.5 to 6.0) using sodium hydroxide and additional dosage of molasses and methanol. The purpose of these treatments was to ensure that the pit water column was in optimum condition for bacterial activity to occur entering the winter of 2002 to 2003. These treatments did have the desired effect. A distinct drop in nitrate/nitrite concentrations was immediately observed. Nitrate/nitrite reached essentially nondetectable levels by approximately March 2003. Physical evidence of sulfate reduction was then observed beginning in April 2003, specifically, the presence of black precipitates and the smell of hydrogen sulfide gas whenever the water was stirred up or agitated.

Concentrations of metals that form metal sulfide precipitates (e.g., copper, cadmium, and zinc) immediately decreased dramatically. The metal-sulfide precipitates were very small and slow-to-settle so that dissolved metals values (i.e., those filtered through a 0.45-μm filter) were much lower than total, unfiltered values. Much of FY03 was spent waiting for these suspended materials to settle. Both total and dissolved metals values gradually decreased through the remainder of FY03. An attempt was made in August 2003 to generate an algae bloom; it was thought that an algae bloom would improve metals concentrations by adsorbing dissolved metals and by "flocculating" suspended metals as the algae died and sank. The algae bloom did not noticeably materialize, possibly due to the system being nitrogen-limited. At the end of FY03, the water in the Anchor Hill Pit met South Dakota requirements for discharge from the site, with the exception of specific conductance, total dissolved solids, total suspended solids, biological oxygen demand, and dissolved oxygen. Dissolved metals analyses met South Dakota requirements for dissolved toxic metals. Total metals values were still significantly higher than the dissolved metals values, as well as being above the discharge criteria for dissolved metals.

Figure 16 presents the average concentrations of nitrate/nitrite and dissolved copper, cadmium, and zinc versus time. As seen in the figure, nitrate/nitrite approached zero in the spring of 2003, and dissolved metals values immediately decreased thereafter as a result of subsequent sulfate reduction. This was encouraging since, thermodynamically, sulfate reduction should not occur until denitrification is complete, and this is exactly what occurred.

Figure 17 presents the average total and dissolved concentrations of copper, cadmium, and zinc versus time. This figure illustrates the significant difference between dissolved and total analyses caused by the presence of small, slow-settling metal sulfide precipitates. It can be seen that both total and dissolved values decreased through the year, and further, so that by the end of the year, acceptable discharge values were reached for dissolved analyses but not for total analyses.

Lastly, Figure 18 presents the alkalinity values obtained. It can be seen that the three deepest sample points have had increasing alkalinity throughout FY03, further confirmation of biological activity. Bicarbonate alkalinity is a product of both denitrification and sulfate reduction.

Vertical profiles obtained indicate that the pit lake has become strongly meromictic, i.e., stratified such that the vertical water column does not mix during the year. This meromictic condition may be used as an advantage in future water treatment efforts. For example, partially neutralized acid rock drainage could be added to the lower depths of the pit, which should remain anoxic and might provide conditions for biological nitrate and sulfate reduction in future water treatment. Plans for FY04 include continuation of monitoring the pit water chemistry, as well as investigating means for subjecting the pit water to ex situ filtration followed by aeration in preparation for possible discharge of a portion of the water contained in the pit.

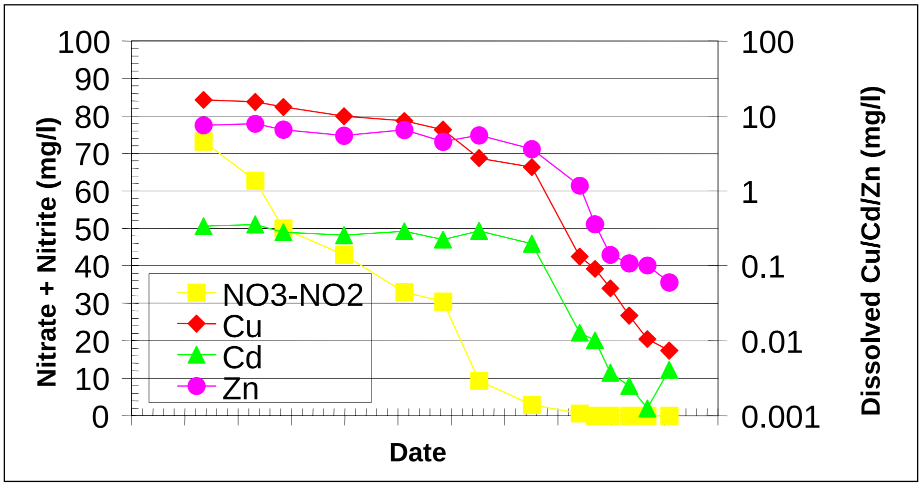


Figure 16. Nitrate/nitrite and dissolved copper, cadmium, and zinc versus time.

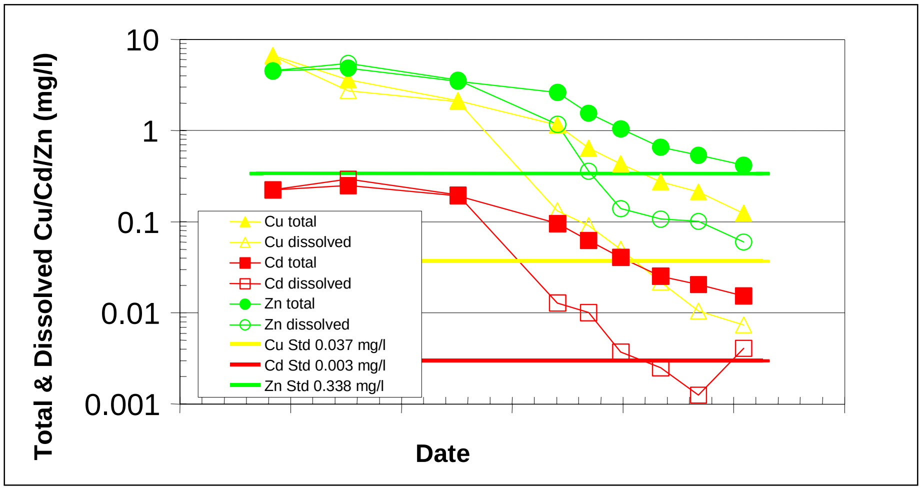


Figure 17. Total and dissolved copper, cadmium, and zinc values versus time.

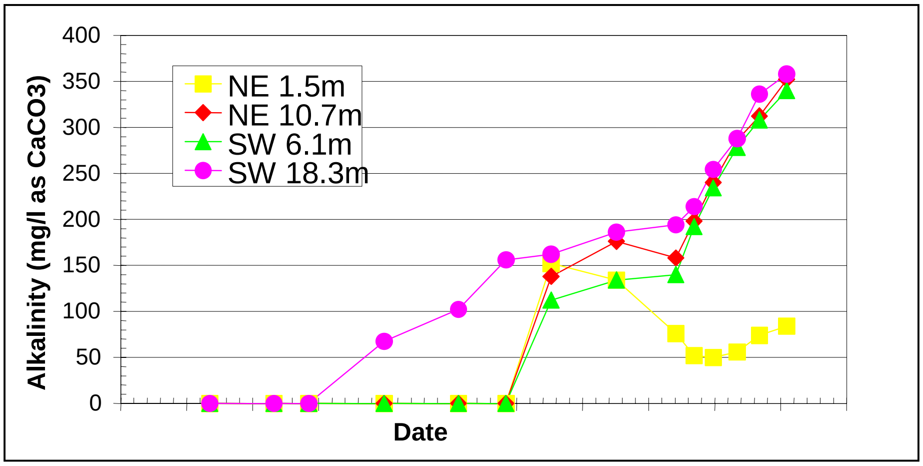


Figure 18. Alkalinity values versus time.

ACTIVITY III, PROJECT 38: CONTAMINANT SPECIATION IN RIPARIAN SOILS DEMONSTRATION

Project Overview

This evaluates phosphorus-lead soil interactions with respect to mineralogical stability. It is an investigation into the reaction processes that take place when phosphate amendments are added to riparian soils containing lead and other solid phase material (i.e., soils, mineral and organic matter).

Technology Description

Phosphorus has shown excellent potential for the remediation of lead-contaminated soils and reduction of lead bioavailability. However, no existing information correlates the reaction mechanisms of lead in field remediated soils with toxicological studies on waterfowl. This project will serve to fill this gap. In addition, this project will also serve to monitor how the speciation and bioavailability of the other contaminants are affected by phosphorus-based remediation treatments.

This study builds upon and links a previously initiated investigation on the ability of phosphate amendments in lead contaminated riparian soils to reduce the bioavailability of lead to waterfowl. Previous work was performed by the Idaho Department of Environmental Quality (IDEQ) and the U.S. Fish and Wildlife Service (USFWS) and was jointly funded by the Coeur d'Alene Basin Commission and U.S. Environmental Protection Agency (EPA). In previous work, different soil amendment treatment technologies were applied at a field site in the Lower Coeur d'Alene River Basin.

Status

The fate of the lead in these previously remediated soils is being investigated. Experiments using advanced spectroscopic and microscopic techniques are being conducted along with an in-vitro test method for simulation of waterfowl digestive systems to demonstrate the effectiveness of phosphate soil amendments to reduce lead bioavailability, solubility, and leachability through the formation of low-solubility lead compounds. This project is scheduled to conclude in June 2005.

ACTIVITY III, PROJECT 39: LONG-TERM MONITORING OF PERMEABLE TREATMENT WALL DEMONSTRATION

Project Overview

The objective of this project was to demonstrate a technology that uses a fishbone apatite treatment media to passively remove zinc from the water. In the initial stages of the project, under U.S. Department of Energy funding, a fully contained subsurface retention basin and treatment system was designed to capture and treat a specified volume of water discharging from the Nevada Stewart Mine. The work scoped under the Mine Waste Technology Program (MWTP) project funding included monitoring the total system and the nearby receiving stream. The MWTP was tasked with defining a baseline metals concentration and then determining the percent reduction of dissolved metals in the effluent from the apatite treatment system over a 2-year period. Flow monitored under this project include the in- and out-flows of the system, and upstream and downstream of the treatment system effluent location.

Technology Description

The Nevada Stewart Mine site is located in Shoshone County near the headwaters of the Highland Creek drainage approximately 5 miles south of Pinehurst, Idaho. This site consists of an adit and several surface waste piles. Approximately 5,200 cubic yards of mine waste were previously removed by the U.S. Bureau of Land Management (BLM) from the site and disposed in the Central Impoundment Area at the nearby Bunker Hill Site. BLM recently contoured the site to prevent erosion and further contaminant loading to the receiving stream, Highland Creek. Approximately 40 to 60 gallons of water discharge continuously from the Nevada Stewart Mine adit into Highland Creek. Analytical results indicate high levels of dissolved zinc, manganese, and iron in the soils and adit discharge.

The technology deployed for this project is an apatite-based treatment media (Apatite II) that passively removes zinc from water (either surface water or groundwater). The treatment media was placed into a fully contained subsurface retention basin and treatment system (see Figure 19). By placing the treatment media into a contained subsurface retention system, several advantages over vault and barrier systems are gained, which include:

- significant odor control;
- protection from freezing;
- protection from vandalism and damage from animals;
- ability to change out treatment media;
- ability to accurately monitor inflow/outflow and water quality to determine metals loading; and
- does not detract from the landscape.

Status

The Nevada Stewart Mine was selected for implementation of the technology in August 2002, and construction of the apatite treatment system was completed at the end of September 2002. Treatment of the Nevada Stewart adit discharge began on October 1, 2002, and the flow through the system was 18 gallons per minute.

The first baseline sample was taken in November 2002 and showed that the system reduced the total metals loading of zinc by 90%, iron by 90%, and manganese by 50%. System monitoring will be performed monthly until September 2004.

After the system operated for a few months, the treatment system plugged. The plugging occurred at the effluent catch basin illustrated in the lower, right corner photo of Figure 19. The geotextile fabric plugged with precipitate suspended in the effluent discharge and bypass mine water. The catch basin was opened and gravel was placed in the system to create a French drain to reduce plugging. Additionally, settling of the apatite media in the treatment cells has reduced the permeability and effectiveness of the treatment system. To reestablish the systems permeability and effectiveness to remove metals, low pressure compressed air was used to agitate the apatite/gravel media. These solutions have worked effectively to reduce plugging and increase the longevity of the treatment system.

After monitoring the apatite system for the initial 9-month period, approximately 162 pounds of zinc, 53 pounds of iron, and 13 pounds of manganese had been removed for the effluent water entering Highland Creek, see Figure 20.

Figure 19. Installation of the fishbone, Apatite treatment system at the Nevada Stewart Mine site.

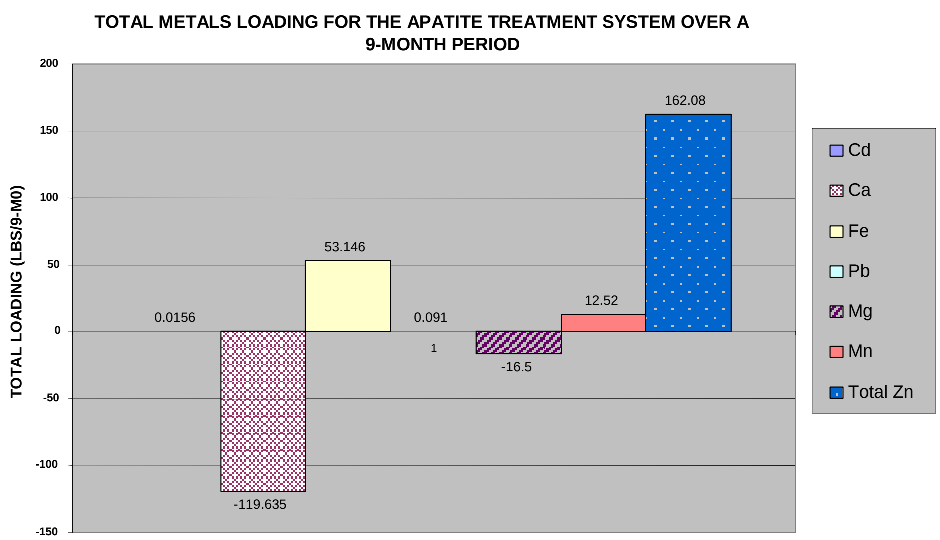


Figure 20. Total amount of metals taken out of the Nevada Stewart Mine water as it flowed through the fishbone apatite system over 9 months.

ACTIVITY III, PROJECT 40: ELECTROCHEMICAL TAILINGS COVER

Project Overview

This project is being conducted at the MSE Technology Applications' (MSE) test facility in Butte, Montana. The purpose of the demonstration is to gather performance information for the electrochemical cover technology developed by Enpar Technologies, Inc., of Guelph, Ontario, Canada. Fresh, nonoxidized tailings along with soil cover were transported from the Golden Sunlight Mine (GSM), owned by Placer Dome, Inc., near Whitehall, Montana. Lined, in-ground test cells, each equipped with a leachate collection system, along with a common sprinkler system, were constructed at MSE's test facility. Two test cells, loaded with tailings and capped with soil cover, were constructed as identical control cells, receiving no electrochemical cover treatment. Two additional test cells, loaded with tailings and capped with soil cover, were constructed as identical test cells and were equipped with the electrochemical enhancement. Equal amounts of water were applied to all four test cells following installation. Water application will continue through the summer of 2004. Leachate will be pumped from each test cell to maintain an artificial water table and to provide water for analytical purposes. Leachate water quality will be monitored by regular sampling and analyses. Oxidation of the acid-generating tailings in all four will be assessed primarily by monitoring sulfate concentrations along with conductivity measurements. Sulfate mass produced by the two cells equipped with electrochemical cover treatment will be compared to that produced by the two control cells with no electrochemical cover treatment. It is anticipated that the two control cells will show higher sulfate concentrations and higher conductivity, resulting from tailings oxidation. The field installation will be monitored for 1 year, at which time it will be dismantled and the tailings returned to GSM.

Technology Description

This technology is intended to be an enhancement of a soil cover to greatly reduce or eliminate the oxidation of sulfide materials, thereby, reducing or eliminating acid rock drainage produced by the covered material. The electrochemical cover consists of sacrificial anodes (e.g., magnesium) overlying the soil cover, which further overlies a cathode consisting of a steel mesh. The soil cover essentially is the conductive dielectric between the cathode and anodes. Oxygen is consumed and alkalinity generated at the cathode by the reaction $O_2 + 2H_2O + 4e^- \Rightarrow 4OH^-$, with the needed electrons produced at the cathode by passive, galvanic corrosion of the anodes. The anodes can be sized so they last for as long as desired; Enpar has typically sized them so they last for 30 to 35 years.

Status

Originally, the project was intended to be conducted at larger scale Tailings Impoundment #1 (GSM). Due to concerns over quantifying oxidation of the dry tailings at Impoundment #1, as well as budgetary limitations, the project was scaled back and rescoped to be conducted under smaller, more controlled conditions at MSE's facility. During FY03, Enpar completed characterization of the Impoundment #1 tailings and soil cover to support design of the field system. Enpar also completed laboratory tests focused on the use of oxidation-reduction potential measurements as an indicator of tailings oxidation; however, this approach was not used due to concerns over the accuracy of the technique. Also in FY03, the project work plan was modified to reflect the new approach at MSE's facility, and the project quality assurance project plan and the field installation were completed. Water was applied to the test cells to "charge" the cells with water, and then the project was shut down for the winter. The test cells equipped with the electrochemical cover treatment have an electrical junction box containing test points that can be used to measure voltage and current values to assess the health of the electrochemical system. Measurements taken in the first month of operation indicated that the system was performing as expected. Plans are to begin applying water and pumping/analyzing leachate in the spring of 2004, continuing doing this through the summer of 2004, then dismantling the system and returning the tailings to GSM in the fall of 2004.

Figure 21 shows the steel mesh cathode placed above the tailings in one test cell. Figure 22 shows the final field installation.

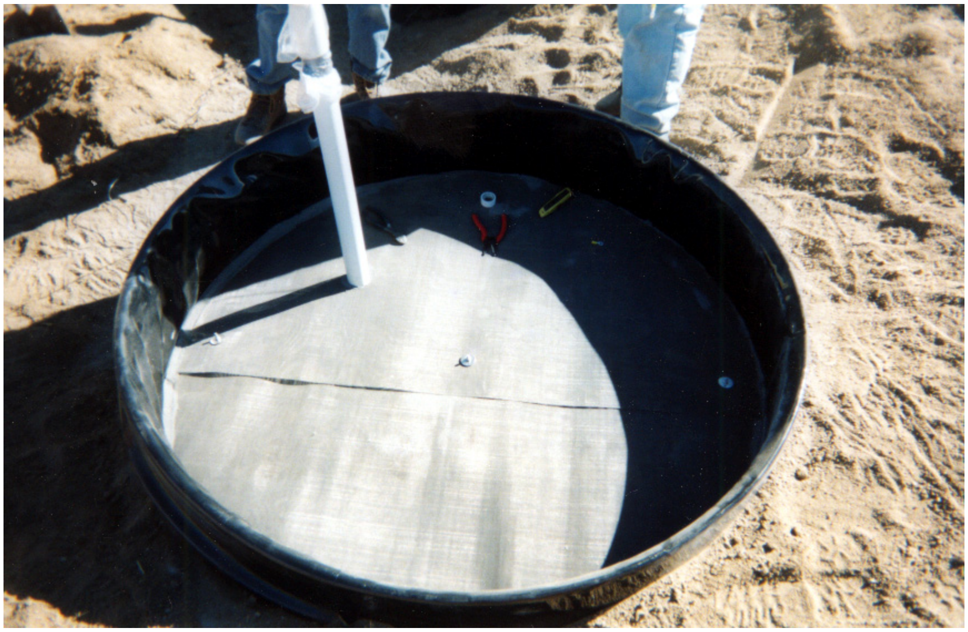


Figure 21. Steel mesh cathode placed on top of tailings in test cell.

Figure 22. Final field configuration.

ACTIVITY IV OVERVIEW—BENCH-SCALE TESTING

The objective of this activity is to develop, qualify, and screen techniques that show promise for cost-effective remediation of mine waste. The most promising and innovative techniques will undergo bench- or pilot-scale evaluations and applicability studies to provide an important first step to full-scale field demonstrations. Each experiment is assigned as an approved project with specific goals, budget, schedule, and principal team members.

ACTIVITY IV, PROJECTS 22 AND 26: ORGANIC MATTER DEGRADATION RATE IN A SULFATE REDUCING WETLAND, PHASES I AND II

Project Overview

The primary objectives for this project were to determine the organic matter decay rate in sulfate reducing wetlands and improve the understanding of how natural wetlands function in metals-contaminated regions. The biodegradable organic matter serves as an indirect carbon and energy source for sulfate reducing bacteria that convert sulfate in the acid mine drainage to sulfide and bicarbonate, which precipitate heavy metals and neutralize acidity. To make quantitative predictions about long-term sulfate reduction rates in constructed wetlands and solid-substrate bioreactors, an effective mathematical model for the system must exist. Sulfate reduction is needed to precipitate heavy metals, and the sulfate reduction rate determines the rate of water treatment. The rate-limiting step in biogenic sulfide production is organic matter degradation. A first order rate coefficient and quantity of organic matter are needed to predict the organic matter replenishment interval that will keep the treatment system operating properly.

Technology Description

Field tests were run in a constructed wetland at the Upper Blackfoot Mining Complex owned by ASARCO near Lincoln, Montana. The rate coefficient was measured by burying dialysis bags made of regenerated cellulose containing compost in a constructed wetland treating acid mine drainage at the Upper Blackfoot Mining Complex. For the laboratory investigation, two reactors (duplicate experiments) were filled with mushroom compost and solution containing 50 milligrams iron per liter and 500 milligrams SO_4^{2-} per liter and kept in an incubator in a laboratory at Montana Tech. Both total organic carbon (TOC) and chemical oxygen demand (COD) were measured over time in samples from the field wetland and laboratory reactors. Other parameters measured included percent volatile solids, carbohydrates, and nonacid soluble matter.

Status

The preliminary results of the 22-month experiment indicated that neither COD nor TOC, measured as milligrams per gram (mg/g) dry compost, changed significantly over the monitoring period, as shown in Figures 23 and 24. Mass balance calculations indicated that the total solids mass, TOC mass, and COD mass of the compost all decreased by about 30%. Preliminary statistical analysis was completed to determine if the COD concentrations of the final samples differed from the COD concentrations of the initial samples. The 95% confidence interval about the mean of the original compost samples minus the mean of the final compost samples was –163 to +131 milligrams COD per dry compost; thus, it was concluded that the COD of the compost did not apparently change significantly during the laboratory experiment. Similarly, for TOC, the 95% confidence interval about the mean of the original compost samples minus the mean of the final compost samples was –19.5 to –6.1 mg TOC per gram dry compost. The statistical analysis appears to suggest that the TOC concentrations of the compost samples increased during the laboratory experiment: however, if the statistical comparison was made using the next-to-last samples instead of the final samples, there would have been no significant change in the compost TOC concentration. Compost samples placed in the operating treatment wetland also experienced no significant change in COD or TOC concentrations over a 12-month period.

There is no mechanistic explanation for TOC concentrations increasing or COD concentrations not decreasing. The most plausible explanations for the possible increase in TOC concentrations and the lack of decrease of COD concentrations are variability among samples and variability among analytical batches. There was no evidence of inaccuracy due to analytical errors in the performance of COD and TOC analyses. Further detailed discussions will be included in the final report. Field and laboratory testing was completed for Phase I and II of this project with the final report expected to be completed in FY04.

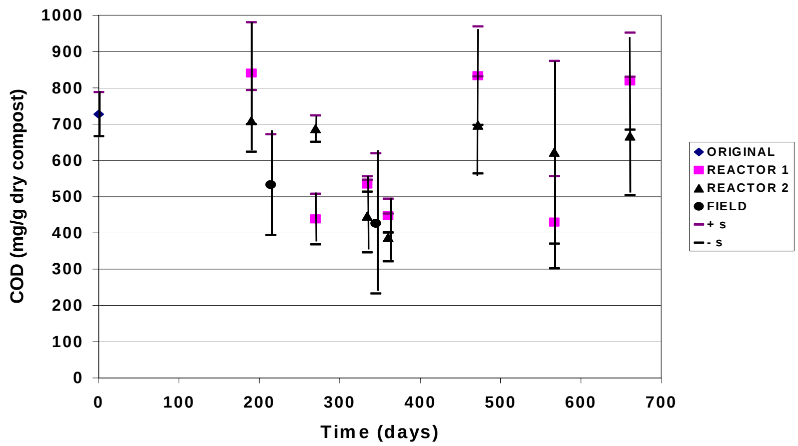


Figure 23. COD concentrations of reactor samples and field samples in milligrams COD per gram dry compost over time. The error bars are ± one standard deviation.

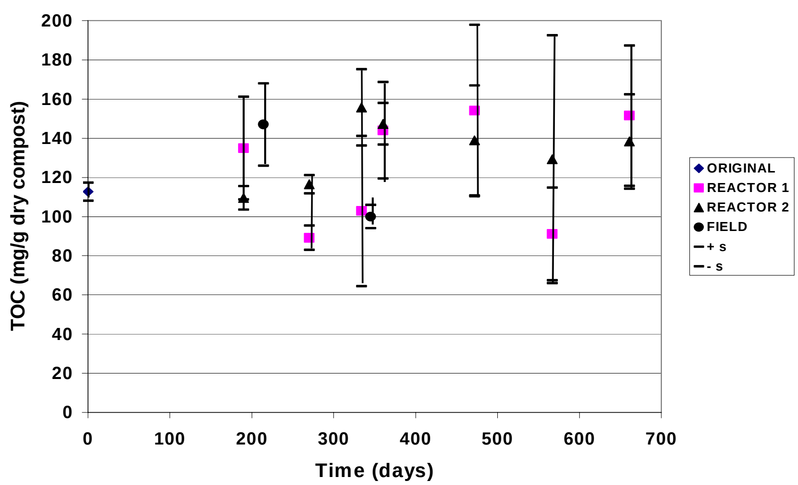


Figure 24. TOC concentrations of reactor samples and field samples in milligrams TOC per gram dry compost over time. The error bars are ± one standard deviation

ACTIVITY IV, PROJECT 23: SULFATE REMOVAL TECHNOLOGY DEVELOPMENT

Project Overview

Numerous mine waters and process effluent waters contain elevated concentrations of sulfate above the Primary Drinking Water Standard (500 milligrams per liter) or the Secondary Drinking Water Standard (250 milligrams per liter). The objective of the sulfate removal technology project was to investigate the use of compound precipitation to remove sulfate through the formation of a solid phase and to investigate the possibility of reducing sulfate to sulfide on a metallic surface (with subsequent precipitation of a metal sulfide). A limited number of technologies are presently used for removing sulfate from wastewater such as bioreduction of sulfate to sulfide and membrane exclusion. These technologies have several disadvantages in that they are relatively expensive to operate, require specialized equipment, require long residence time reactors (bioreduction), high pressure (membrane processes like reverse osmosis and nano-filtration), and have difficult solid/liquid separations and membrane fouling problems.

Technology Description

Two technological approaches for lowering sulfate were investigated for this project including precipitation of sulfate bearing compounds and electrochemical metal reduction of sulfate. The goal of the experimental study was to achieve a sulfate concentration of less than 250 milligrams per liter.

Status

The project final report is in the final stages of review; however, testing and data analysis was completed to investigate both the compound precipitation and electrochemical metal reduction methods for removing sulfate from wastewater. Results from initial geochemical modeling and literature reviews identified Alunite and Ettringite as possible compounds for the reduction of sulfate using the compound precipitation method. After preliminary scoping experiments were performed, Ettringite was selected for further detailed study. The preliminary tests showed that the important variables for the formation of Ettringite were aluminum concentration, calcium hydroxide concentration, and time of contact. The system was then investigated using a ½ replicate of a 2^4 factorial experimental design to delineate the importance of each of four selected variables. The ½ replicate of a 2^4 factorial experimental design is a one-half replica study (for four variables) and requires eight experiments.

The design matrix studies illustrated that sulfate can be effectively lowered to the goal level in reasonable residence times. During the matrix experimental design studies, effective SO_4 removal was achieved not only for high SO_4 bearing solutions (near 5 g/L) but also for low SO_4 bearing solutions (near 0.4 g/L). Regression equations generated from this investigation demonstrated that SO_4 removal is a rather complex precipitation process that depends significantly on various variables including the initial SO_4 concentration, amounts of sodium aluminate and hydrated lime, and various binary interaction parameters, and in some cases residence time. The experimental conditions that produce effective SO_4 removal were verified by equilibrium modeling. In addition, four different wastewaters containing different levels of sulfate were treated by compound precipitation. The experimental results showed that sulfate concentrations were reduced below the goal limit of <250 milligrams per liter for all the treated waters.

On the other hand, based on the electrochemical experiments, it is clear that electrochemical metal reduction of sulfate to sulfide is not an appropriate technology for controlling sulfate concentrations in acid mine drainage or other effluent discharge waters. Even though thermodynamic calculations predict that sulfate should be reduced by the potentials established in a solution by the presence of elemental iron, the results of the electrochemical reduction experiments showed that sulfate reduction was unsuccessful. Further test work also demonstrated that sulfate cannot be reduced to sulfide or bisulfide even on a platinum surface. Other investigators have proposed that this effect can be explained by the metastability of sulfate, i.e., kinetically the reduction of sulfate to form the thermodynamically favored equilibrium species (sulfide or bisulfide) is very slow. In this regard, precipitation (i.e., Ettringite precipitation) would be a better treatment technology. The final report will be finalized and completed in early FY04.

ACTIVITY IV, PROJECT 24: ALGAL BIOREMEDIATION OF THE BERKELEY PIT LAKE SYSTEM–PHASE III

Project Overview

The Berkeley Pit Lake is a former open-pit copper mine that operated between 1955 and 1982. In 1982, the mine's dewatering pumps were shutoff, and the pit began filling with acidic water, which is currently rising at a rate of about 4 meters (m) per year. The Berkeley Pit Lake is approximately 542 m deep and 1.8 kilometers (km) across. In 1984, the Berkeley Pit was designated as a CERCLA Superfund site by the U.S. Environmental Protection Agency (EPA). Other important aspects of the Berkeley Pit Lake include low acidic pH values (pH 2.5 to 3.0) and high concentrations of various heavy metals. Previous and ongoing Mine Waste Technology Program research has been investigating the intricacies of the microbial ecology of the Berkeley Pit Lake system such as the diversity of algae, protistans, fungi, and bacteria that inhabit the pit lake.

Technology Description

This project was to further investigate some of the previously isolated extremophiles (specifically algae) from the Berkeley Pit Lake system that may be used as a potential solution for bioremediation. More specifically, the project objectives were as follows: 1) to evaluate the bioremediative potential of the four most rapidly growing species in the Berkeley Pit Lake System; 2) to determine which combination of nutrients will stimulate growth of the best bioremediator of the four isolated species; 3) to determine a temperature profile for the four species to determine their optimal growth temperature; 4) to continue to isolate organisms and determine their bioremediative potential; and 5) monitor algal and bacterial counts from a profile of Pit Lake System waters.

Status

Applicable laboratory testing and data analysis is complete for this project, and the final report is being prepared, which is expected to be finished early FY04. Various data collection activities included separating bacteria from algae by washing through a filter and centrifugation and determining metal/element uptake potential by measuring dissolved metal concentrations before and after adding microorganisms to Berkeley Pit Lake water.

Algae isolated from the Berkeley Pit Lake, maintained in culture in the Montana Tech of the University of Montana Microbiology Laboratory, were used to obtain uni-algal axenic cultures to investigate metals removal capacity. Two algal species were used: *Chlamydomonas acidophila* Negoro *and Chromulina freiburgensis* Dofl. A total of two types of high-density cultures were obtained from the uni-algal cultures of *Chlamydomonas acidophila* and *Chromulina freiburgensis,* and uni-algal cultures of the same species but containing bacteria. Aspirator bottles containing Modified Acid Medium (MAM) were inoculated with *Chromulina freiburgensis* and *Chlamydomonas acidophila* and incubated in the growth chamber. Population levels and the purity of cultures were verified by counting the algae and the incidental bacteria. As a result, four types of high-density cultures were obtained as follows: 1) pure (axenic) *Chromulina freiburgensis* in MAM; 2) *Chromulina freiburgensis* and associated bacteria; 3) pure (axenic) *Chlamydomonas acidophila; and 4) Chlamydomonas acidophila* and associated bacteria.

The experiment was designed to determine if any difference may exist (if there is a difference) between the bioremediation capacity of the pure algal cultures and that of mixed cultures containing algae and bacteria that were exposed to Berkeley Pit water. The experimental matrix consisted of two factors (bacteria and species), each of which had two levels. The species factor was *Chlamydomonas acidophila* as one level and *Chromulina freiburgensis* as the second level, and the bacteria factor was pure algae cultures (no bacteria) as one level and mixed algae and bacteria cultures as the second level. This resulted in a randomized design with a 2-by-2-factorial treatment. The experiments carried out suggested that the various species of organisms examined that live in the Berkeley Pit lake are metal tolerant species and accumulate metals. The results of the statistical analysis revealed a significant difference between the initial and final concentration for all of the four treatments for aluminum, iron, manganese, and zinc. For copper, the statistical analysis results show a significant difference between the initial and final concentration for both *Chromulina freiburgensis* in pure culture and *Chromulina freiburgensis* with bacteria but no significant difference for *Chlamydomonas acidophila* in pure culture and *Chlamydomonas acidophila* with bacteria. The difference between the initial and final concentration of magnesium was statistically significant for *Chromulina freiburgensis* in pure culture and *Chlamydomonas acidophila* with bacteria, but not for *Chromulina freiburgensis* with bacteria and *Chlamydomonas acidophila* in pure culture. Finally, no statistically significant difference was shown for nickel for any of the four treatments except for *Chromulina freiburgensis* with bacteria treatment.

Based on the data collected within this experiment, it appears that when Berkeley Pit water is inoculated with *Chlamydomonas acidophila* a higher amount of metals is found in the filtrate fraction than with *Chromulina freiburgensis.* As such, it would appear that *Chlamydomonas acidophila* is a better remediator than *Chromulina freiburgensis* for most all the metals analyzed in this experiment. To evaluate the effect of bacteria on the metal concentration in the solution of Berkeley Pit water and algae, the metals concentrations were compared for solutions that contained algae in pure cultures and solutions with algae and bacteria. Probability values resulting from the statistical analysis showed that the bacteria factor does have a significant effect on the concentration of most metals in the filtrate fraction but only for copper, iron, and magnesium for the filter fraction. Thus, these results appear to reveal that a mixed algae and bacteria culture added to the Berkeley Pit filtered water can ad/absorb more metals than a culture of algae that does not contain bacteria (axenic culture). One explanation for this result could be that the surface area available with sorption sites provided by bacteria is larger than the surface area provided by algae cells.

ACTIVITY IV, PROJECT 25: HEAVY AND TOXIC METAL REMEDIATION USING REDUCTIVE PRECIPITATION/CEMENTATION

Project Overview

The main objective of this study was to develop an appropriate technology for treating a variety of contaminated waters (i.e., groundwater, surface water, and acid mine water) by validating the concept of reductive precipitation/cementation for removing heavy metals specifically cadmium, copper, nickel, lead, and zinc.

Technology Description

Reductive precipitation consists of using elemental iron to control the solution potential at a level that is favorable for removing heavy metals by precipitation as metal sulfides while reductive cementation refers to the direct electrochemical reduction of the metal. Both removal processes were to occur simultaneously during the treatment of heavy metal bearing waters such as acid mine waters (i.e., Berkeley Pit Lake water). Previous studies have demonstrated on a laboratory scale that zero valence iron is effective in removing metals such as arsenic, selenium, thallium, and mercury.

Status

Most of the laboratory testing was completed for this project, and the final report is expected to be finished in FY04. A full two-level design matrix test series using sodium sulfide as the reagent was conducted for this investigation. Generally, the design matrix tests consisted of eleven experiments (i.e., eight required by the design matrix, two midpoint tests, and one without iron) to investigate the influence of sodium sulfide, time, and pH on removing heavy metals cadmium, copper, nickel, lead, and zinc. Preliminary analysis of the experimental design matrix work on pretreated Berkeley Pit Lake water revealed that the regulatory effluent goal treatment requirements were met for all metals except for zinc. Further testing revealed the removal of nickel and zinc was apparently not as effective in the absence of iron. A more in-depth evaluation and analysis of the data will be provided in the final report.

ACTIVITY IV, PROJECT 27: SUBAQUEOUS OXIDATION OF PYRITE AND STABLE ISOTOPE GEOCHEMISTRY OF AN ACIDIC PIT LAKE

Project Overview

Subaqueous disposal of pyrite-rich mine waste is a common method of preventing acidic mine drainage. It is reasoned that, by inundation with water, the rate of oxygen (O_2) ingress to the waste is drastically reduced, thereby effectively stopping the pyrite oxidation reaction. It is less widely known that pyrite can also be oxidized by dissolved ferric iron (Fe^{3+}). Previous laboratory experiments have shown that if pyrite is oxidized, a significant percentage of the oxygen molecules in the sulfate produced are inherited from atmospheric O_2. In contrast, for anaerobic pyrite oxidation, molecular oxygen is absent, so that 100% of the oxygen atoms in the sulfate produced must come from the water itself. The primary interest for this research project is the Berkeley Pit Lake in Butte, Montana. The Berkeley Pit Lake is a former open-pit copper mine that operated between 1955 and 1982. In 1982, the mine's dewatering pumps were shut off, and the pit began filling with acidic water. In 1984, the Berkeley Pit was designated as a Superfund site by the U.S. Environmental Protection Agency (EPA).

Technology Description

This research was divided into two subprojects. Subproject 1 involved bench-scale experiments aimed at quantifying subaqueous pyrite oxidation rates by ferric iron, using control samples of pure pyrite, as well as actual wallrock material and water from the Berkeley Pit Lake in Butte, Montana. Subproject 2 involved collecting a suite of stable isotope analyses (S and O) of water and aqueous sulfate from the Berkeley Pit Lake, waters emptying into the Berkeley Pit Lake, and selected laboratory experiments.

The main objective of Subproject 1 was to demonstrate the potential importance of subaqueous pyrite oxidation by Fe^{3+}, with special attention to the possible role this process plays in the generation of acid in pit lakes. The main objective of Subproject 2 was to use stable isotopes to help elucidate the primary mechanism of pyrite oxidation in the Berkeley Pit Lake (i.e., aerobic versus anaerobic).

Status

Field sampling and most laboratory testing was completed for this project, and the final report is expected to be completed in FY04. Preliminary analysis of the data (from bench-scale experiments aimed at quantifying subaqueous pyrite oxidation rates of shallow Berkeley pit water) revealed that pyrite oxidation rates in pit water are similar to those using synthetic iron chloride solutions, which suggests that the presence or absence of other metals does not greatly change the pyrite oxidation rates. In addition, it was observed that during pyrite oxidation experiments using deep Berkeley Pit water, [under cold (5 °C) conditions], rates of pyrite oxidation by Fe^{3+} were slower than using shallow pit water under ambient temperature (20 °C) conditions.

Preliminary results of the S and O isotopic compositions of the mine waters sampled in this study show a clear evaporation trend. Samples that have undergone the greatest percent evaporation come from the shallow Berkeley Pit Lake. The deep Pit Lake and Horseshoe Bend influent waters appear to have identical isotopic signatures and indicate an intermediate degree of evaporation. Shaft waters show the least amount of evaporation and compare fairly close to the meteorological water line for average precipitation in Butte. The O-isotopic composition of sulfate in the Berkeley Pit Lake is consistent with an anaerobic pyrite oxidation model. This supports the general hypothesis that the sulfate and acid in the Berkeley pit may be derived by subaqueous oxidation of pyrite by Fe^{3+}; however, because the isotopic relationships are very complex, it is not proof that this is the case.

ACTIVITY IV, PROJECT 28: EFFECTS OF PLANT SPECIES AND RODENTS ON THE SEQUESTRATION AND/OR MOVEMENT OF MERCURY FROM RECLAIMED SITES

Project Overview

Mercury has been used to amalgamate precious metals throughout recorded history and was used extensively in the Western United States gold fields including Montana. During the period from 1850 to 1900, it is estimated that gold mining consumed 70,000 tons of mercury. The overall efficiency of mercury utilization/ recovery in gold processing was low and most estimates reveal a mass loss of mercury at least equivalent to the mass of gold recovered. As a result of the low recovery, mercury has created a variety of environmental concerns. A scenario for the movement of mercury in the environment from mining wastes or from repositories is the initial uptake and accumulation in vegetation followed by the consumption of vegetation by herbivorous organisms.

The objective of this project was to examine this scenario by determining the uptake of mercury by selected plant species and the possible movement of mercury from plants to higher level consumers such as mice. This project examined the mercury levels in vegetation and mice associated with mercury contaminated and noncontaminated (or control) sites. Contaminated sites in Montana include the

Silver Creek Drainage near Marysville, Montana, and the High Ore Creek repository near Boulder, Montana. A noncontaminated (or control) site was also included in this study.

Technology Description

Part I of this research examined the root/shoot ratios of mercury in four commonly used reclamation species in the greenhouse as well as from other woody and nonwoody species currently growing on mine wastes in the Silver Creek Drainage. Part II of this research project examined mice from a mercury contaminated mine drainage (i.e., Silver Creek Drainage) and from noncontaminated sites (i.e., Ranch Site) to determine if mice represent a pathway for environmental mercury transport. Mouse hair was used as an indicator because mercury is readily deposited into hair and stays for a comparatively long time. Small mammals (i.e., rodents) were used for ecological monitoring because they are small, easy to handle, and spend their entire life cycle within a relatively small area (usually even within small impacted areas such as mine sites).

Status

Field investigation and laboratory testing was completed for this project, and the final report is expected to be completed in FY04. The preliminary results reveal that the grass species sampled, and growing on the most contaminated site, were not accumulating substantial amounts of mercury in either their roots or leaves. Two tree species were also sampled: Ponderosa pine and Douglas fir. The Ponderosa pines sampled did not accumulate mercury in either roots or needles, but the Douglas fir trees sampled did accumulate mercury in roots but not needles. Two shrub species were also sampled, and a few plants of both species accumulated mercury in their roots. The repository site had very low levels of mercury in cover soil, grass roots and leaves, and in mouse hair. Hence, this repository appears to be preventing the movement of mercury into the surrounding biota.

The results also show that mice can be used as a bioindicator for potential mercury contamination. Mice from the contaminated Silver Creek Drainage and from the Ranch Site approximately 3 miles from Silver Creek accumulated mercury in their hair. Average measured mice hair mercury concentrations at Silver Creek Drainage and Ranch Site were 4.47 and 5.15 µg/g, respectively. Mice from the repository and from a more distant ranch site had much lower hair mercury levels (average of 0.81 to 0.82 µg/g) as did the cover soil at the repository. A conclusion from these results is that, to date, the repository has prevented mercury in the repository tailings from entering the mice ecosystem and that the engineering design used has effectively isolated the mercury in the tailings. Since mice are relatively easy to capture, they could be used as a relatively low cost and long term biological monitor for sites constructed to isolate mercury containing wastes.

A secondary purpose of the study was to determine the uptake of mercury by grass species grown under controlled greenhouse conditions. Four species of grass recommended for possible use as reclamation species in the Butte/Anaconda area were tested. None of the four species accumulated mercury from spiked soils (similar to the species from the contaminated field site) and appear to be suitable for revegetation on sites with elevated mercury levels.

ACTIVITY IV, PROJECT 29: FIELD MONITORING AND EVALUATION OF RECLAMATION STRATEGIES OF ABANDONED MINE SITES IN THE HELENA NATIONAL FOREST

Project Overview

The main purpose of this project was to help evaluate the effects of previously selected remediation methods on both abandoned upland as well as wetland mine sites. For this investigation, field tests were completed at three reclaimed mine sites in the Helena National Forest: the Ontario Mine, Armstrong Mine, and Upper Valley Forge Mine. All of the sites are located west of Helena, Montana, and south of Elliston, Montana, and State Highway 12 in the Helena National Forest. There were two wetland sites studied at both the Ontario Mine and the Upper Valley Forge Mine, and there were two upland sites studied at each of the three locations. The wetland sites are located along stream banks that had been previously covered in mine tailings.

Recent reclamation activities conducted by the U.S. Forest Service removed the actual tailings; however, the native ground underneath appears to be still contaminated with elevated levels of metals. Typically, the sites under investigation contained reclaimed waste rock piles and reclaimed tailings piles.

Technology Description

For this investigation, the movement of contaminants across the interface between supposed clean fill materials and the contaminated substrates were monitored with Unibest PST-1 resin capsules. The Unibest PST-1 resin capsule is designed to mimic plant roots and adsorb bioavailable elements and compounds. Each of these capsules contains thousands of resin beads charged with hydrogen (H^+) and hydroxide (OH^-) ions held within a porous fabric membrane. The mixed-bed resins act as a strong sink for ions from soil solution. The amount of each ion adsorbed by a resin capsule during a specific amount of time depends on the initial soil concentration of each ion, the diffusion rate of each ion through the soil, and the capsule surface area in contact with the soil. The contents of the resin capsules were analyzed for dissolved arsenic, cadmium, copper, lead, zinc, and iron. Trends in metal concentrations over the course of the study will be evaluated and compared.

Status

Field monitoring and most of the laboratory testing were completed for this project, and the final report is expected to be finished in FY04. Ion resin capsules were collected and analyzed for metals approximately every 4 weeks from June 2003 through November 2003 at each of the sites. Preliminary graphical analysis of the ion resin capsule data (as a percentage of the initial soil concentration) from the Upper Valley Forge wetland site is provided in Figures 25, 26, and 27. In general, the trends observed in the data collected for the Upper Valley Forge upland and wetland sites were similar with higher metals levels being adsorbed at the wetland sites. The quality of metals adsorbed by the capsules in the contaminated layer are relatively similar to the other soil/waste layers, which appears to suggest that groundwater flowing through the site is a source of metals being adsorbed by the resin capsules. Overall, the effectiveness of the reclamation methods appeared to be variable based on the information collected. At wetland sites, the reclamation work did not appear to reduce metal movement as observed from the high rate of metal movement into the resin capsules relative to the initial soil concentrations. However, metal concentrations adsorbed by the resin capsules in the upland sites were low, which would seem to indicate the reclamation was effective in preventing metal movement during the monitoring period.

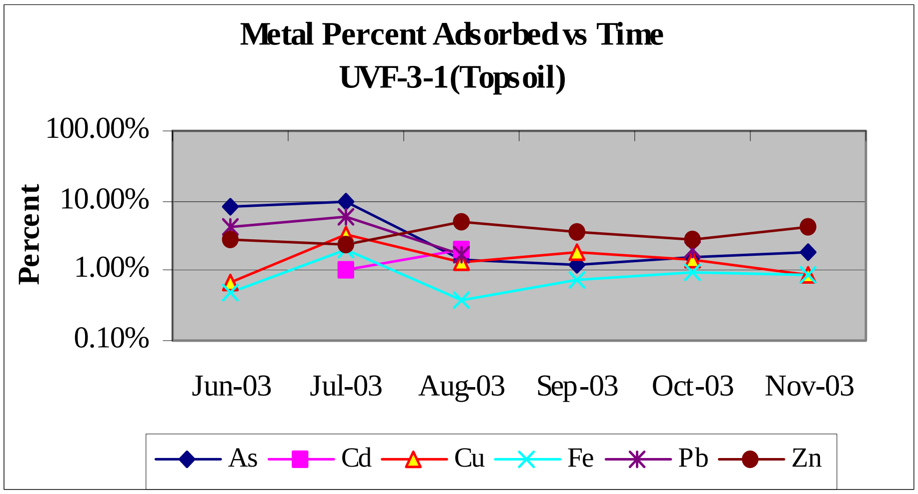


Figure 25. Metal Adsorption Percentage at Upper Valley Forge UVF-3-1.

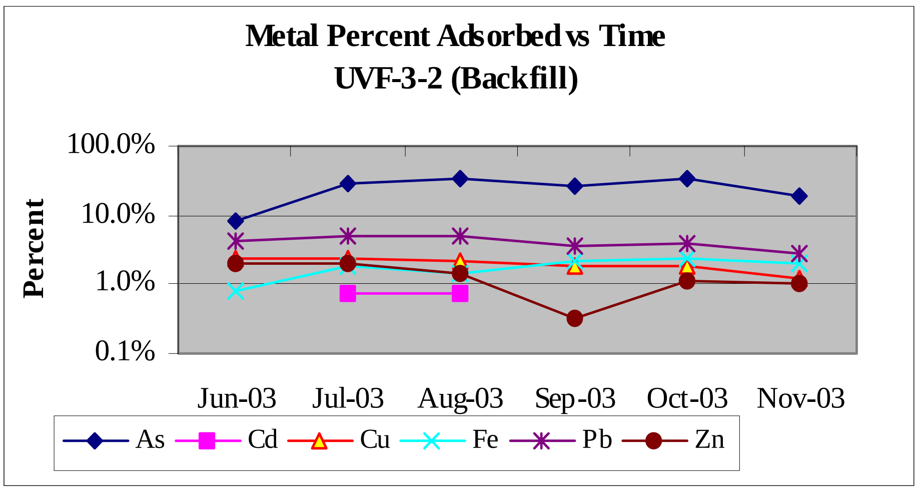


Figure 26. Metal Adsorption Percentage at Upper Valley Forge UVF-3-2.

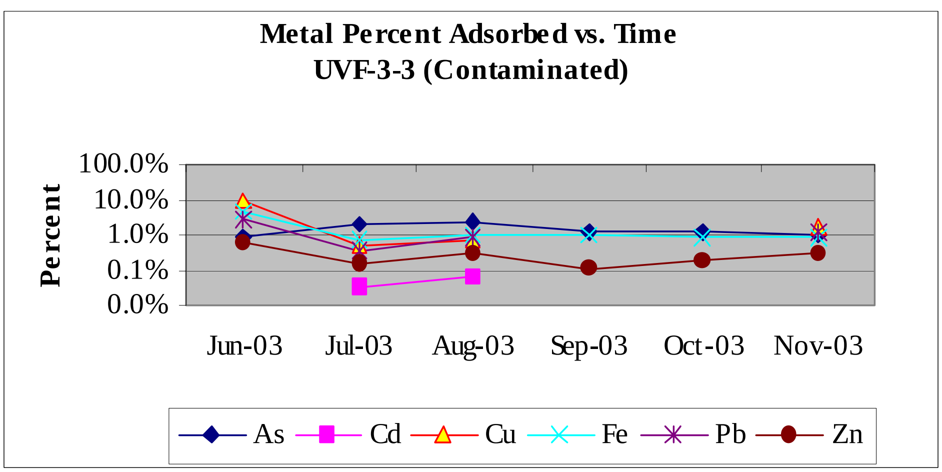


Figure 27. Metal Adsorption Percentage at Upper Valley Forge UVF-3-3.

ACTIVITY V OVERVIEW—TECHNOLOGY TRANSFER

This activity consists of making technical information developed during Mine Waste Technology Program (MWTP) activities available to industry, academia, and government agencies. Tasks include preparing and distributing MWTP reports, presenting information about MWTP to various groups, publications in journals and magazines, holding Technical Integration Committee meetings, sponsoring mine waste conferences, and working to commercialize treatment technologies.

Fiscal Year Highlights

- The MWTP Annual Report was published summarizing fiscal year accomplishments. A similar report will be published each year.

- Several MWTP professionals appeared at various meetings to discuss the Program with interested parties. MWTP personnel attended and presented papers at many mine waste conferences, as well as mining industry meetings.

ACTIVITY VI OVERVIEW—TRAINING AND EDUCATION

Through its education and training programs, the Mine Waste Technology Program (MWTP) continues to educate graduate students in the Mine and Mineral Waste Emphasis Program, professionals, and the general public about the latest information regarding mine and mineral waste cleanup methods and research.

As a result of rapid technology and regulatory changes, professionals working in the mine- and mineral-waste areas often encounter difficulties in upgrading their knowledge and skills in these fields. In recent years, the environmental issues related to the mining and mineral industries have received widespread public, industry, and political attention. While knowledge of current research and technology is vital for dealing with mine and mineral wastes, time and costs may prevent companies from sending employees back to the college classroom.

Through traditional college coursework, short courses, workshops, conferences, and video outreach, Activity VI of MWTP educates professionals and the general public and brings the specific information being generated by bench-scale research and pilot-scale technologies to those who work in mine- and mineral-waste remediation.

Fiscal 2003 Highlights

- Montana Tech of the University of Montana (Montana Tech) took a leading role in the implementation of the Workshop on Mining Impacted Native American Lands in Reno Nevada, conducted September 9 through 11. A variety of issues were presented and discussed, including cultural issues, trust issues, specific case studies, environmental and human health, water impacts, and remediation and reclamation activities. Approximately 200 were present for the workshop with approximately 30 guest speakers.
- Hardrock Mining 2002, conducted in May 2002, was an opportunity to examine and discuss current and future environmental issues shaping the mining industry with an emphasis on case study analysis and technology verification. The U.S. Environmental Protection Agency's (EPA) Office of Research and Development and EPA's National Risk Management Research Laboratory (NRMRL) sponsored the 3-day event. MWTP provided funding and sponsorship. Attendees exchanged scientific information serving to enhance remediation and cleanup of both legacy and current mining wastes and to contribute to a sustainable U.S. modern mining industry. NRMRL's Technology Transfer staff completed a CD that includes the conference

materials, presentations, posters, and transcripts of plenary speakers. Call (513) 560-7804 to obtain the CD.

- The Mine Design, Operations, and Closure Conference 2003, conducted in April 2003, continued last year's interagency cooperation. The 5-day event was cosponsored by the U.S. Forest Service; U.S. Bureau of Land Management; Montana Department of State Lands; MSE Technology Applications, Inc.; Haskell Environmental Research Studies Center;

  several other private companies; and Montana Tech. During the conference, experts presented overviews on such topics as predictive chemical modeling for acid mine drainage, mine water quality source control, state-of-the-art containment technologies, and innovative pit reclamation. Over 150 mine operators, consultants, and professionals from the private and public sectors attended the conference.
- The Mine and Mineral Waste Emphasis Program has an enrollment of 11 students with all of them receiving funding from MWTP. This is an interdisciplinary graduate program that allows students to major in their choice of a wide variety of technical disciplines while maintaining an emphasis in mining and mineral waste.
- Mine and Mineral Waste Emphasis graduate students from Montana Tech attended the Mine Design, Operations, and Closure Conference 2003 in Polson.
- Graduate students in the Mine and Mineral Waste Emphasis Program are working on projects in Activities IV.
- As part of the Native American Initiative, Montana Tech presented a variety of short courses: Mining and the Environment, Acid Rock Drainage, Mining Hydrology, and Hazwoper at Fort Belknap. Hazwoper was provided so that the Native Americans could participate in the reclamation cleanup on the mine site. An environmental learning community was set up to house the short courses and Web courses to make them accessible to Native American communities around the country. Available courses include Acid Rock Drainage, Environmental Planning, Mining and the Environment, Golf Course Planning, Trailways, Hazwoper, Hazardous Materials Management, Geographical Information Systems, Ecosystem Management, Water Resources, and Alternative and Innovative Treatment Technologies.

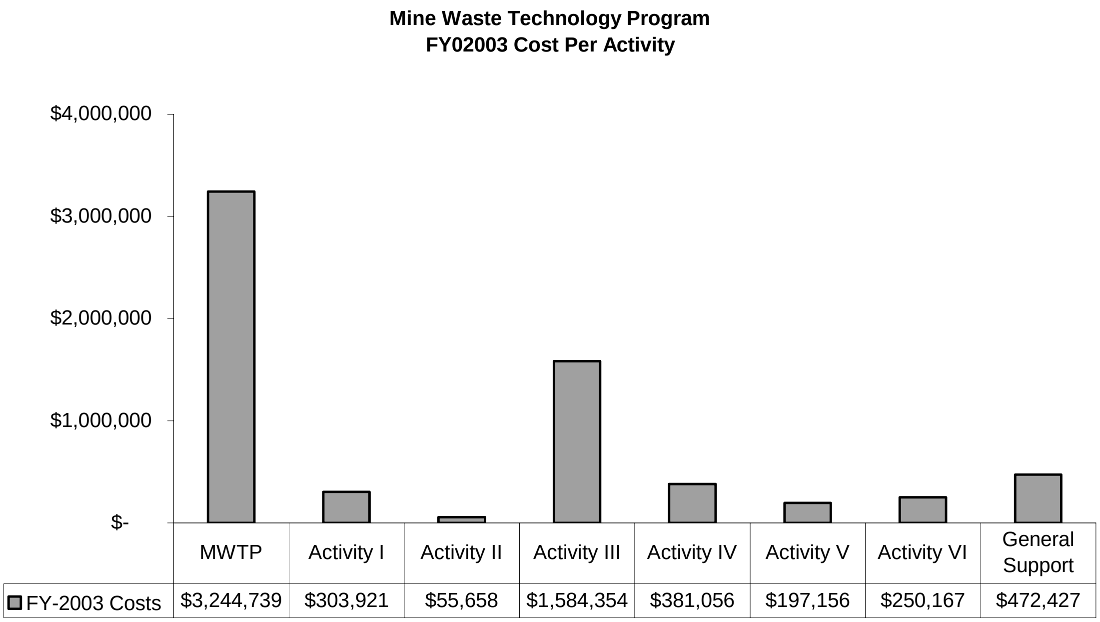
Future Activities

The following training and educational activities are scheduled for 2004:

- MWTP Training and Education program will offer the Mine Design, Operations, and Closure Conference in April 2004.
- MWTP Training and Education program will participation in the Battelle Technology Conference in May 2004
- MWTP Training and Education program personnel will be on the steering committee for the Pit Lakes Conference in the fall of 2004.

FINANCIAL SUMMARY

Total expenditures during the period October 1, 2002, through September 30, 2003, were $3,244,739, including both labor and nonlabor expense categories. Individual activity accounts are depicted on the performance graph in Figure 28.



	MWTP	Activity I	Activity II	Activity III	Activity IV	Activity V	Activity VI	General Support
FY-2003 Costs	$3,244,739	$303,921	$55,658	$1,584,354	$381,056	$197,156	$250,167	$472,427

Figure 28. Mine Waste Technology Program fiscal 2003 performance graph, costs per activity.

COMPLETED PROJECTS

For information on the following completed Mine Waste Technology Program projects, refer to the web site: http://www.epa.gov/ORD/NRMRL/std/mtb/mwtphome.html.

Activity III (Demonstrations)

Project 1	Remote Mine Site
Project 2	Clay-Based Grouting
Project 4	Nitrate Removal
Project 5	Biocyanide
Project 6	Pollutant Magnet (canceled)
Project 7	Arsenic Oxidation
Project 9	Arsenic Removal
Project 10	Surface Waste Piles—Source Control
Project 11	Cyanide Heap Biological Detoxification
Project 12	Sulfate-Reducing Bacteria Reactive Wall
Project 12A	Calliope Mine Internet Monitoring System
Project 13	Hydrostatic Bulkhead with Sulfate-Reducing Bacteria (canceled)
Project 14	Biological Cover
Project 16A	Sulfate-Reducing Bacteria-Driven Sulfide Precipitation
Project 17	Lead Abatement
Project 18	Gas-Fed Sulfate-Reducing Bacteria Berkeley Pit Water Treatment
Project 19	Site In Situ Mercury Stabilization Technologies
Project 20	Selenium Removal/Treatment Alternatives
Project 22	Phosphate Stabilization of Mine Waste Contaminated Soils
Project 23	Revegetation of Mining Waste Using Organic Amendments and Evaluate the Potential for Creating Attractive Nuisances for Wildlife
Project 25	Passive Arsenic Removal
Project 27	Remediating Soil and Groundwater with Organic Apatite
Project 31	Remote Autonomous Mine Monitor
Project 35	Biological Prevention of Acid Mine Drainage (Gilt Edge Mine)
Project 36	Ceramic Microfiltration System

Activity IV

Project 1	Berkeley Pit Water Treatment
Project 2	Sludge Stabilization
Project 3	Photoassisted Electron Transfer Reactions Research
Project 3A	Photoassisted Electron Transfer Reactions for Metal-Complexed Cyanide
Project 3B	Photoassisted Electron Transfer Reactions for Berkeley Pit Water
Project 4	Metal Ion Removal from Acid Mine Wastewaters by Neutral Chelating Polymers
Project 5	Removal of Arsenic as Storable Stable Precipitates
Project 7	Berkeley Pit Innovative Technologies Project
Project 8	Pit Lake System—Characterization and Remediation for the Berkeley Pit
Project 9	Pit Lake System—Deep Water Sediment/Pore Water Characterization and Interactions
Project 10	Pit Lake System—Biological Survey of Berkeley Pit Water
Project 11	Pit Lake System Characterization and Remediation for Berkeley Pit—Phase II
Project 12	An Investigation to Develop a Technology for Removing Thallium from Mine Wastewaters

Project 13	Sulfide Complexes Formed from Mill Tailings Project
Project 14	Artificial Neural Networks as an Analysis Tool for Geochemical Data
Project 16	Pit Lake System Characterization and Remediation for Berkeley Pit—Phase III
Project 17	Mine Dump Reclamation Using Tickle Grass Project
Project 18	Investigation of Natural Wetlands Near Abandoned Mine Sites
Project 19	Removing Oxyanions of Arsenic and Selenium from Mine Wastewaters Using Galvanically Enhanced Cementation Technology
Project 20	Algal Bioremediation of Berkeley Pit Water, Phase II

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